Paper Flight

Epic Long Distance Flyers

6 Models of Famous Aircraft - Easy to build and trim
Created in CAD - Aeronautically Engineered
Designed to fly up to 100+ meters with ease !

M.J. La Grange

Paper Flight by M.J. La Grange, Published by Paper Flight Publishing Ltd., Auckland, New Zealand.

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About the Author

Martin J. La Grange was born in Stellenbosch, South Africa. He has been fascinated with airplanes from a very young age, building his first paper airplane at age 4, and learned his skills in model design from his father, P.B. La Grange.

Martin has been building model airplanes ever since, and builds in paper, balsa, scale plastic, and flies radio control slope scale sailplanes.

Martin studied at the University of Stellenbosch, graduating with a conjoint BSc. in Food Science and Biochemistry in 2001. His studies did include thermodynamic engineering, and CAD, which he has been applying to his hobbies.

Martin runs his own CAD engineering studio, where he designs for the automotive, aerospace, marine & agriculture industries. He also produces high-end technical illustrations, as well as provides 3D printing services in industrial materials.

Martin lives in Auckland, New Zealand.

Dedication

The models in this book are the culmination of the application of engineering design to the paper aircraft, over the last 50 years.

Before their work, there had been very little science applied to paper aircraft - they were folded origami, a tradition of thousands of years (and for the same period the only heavier-than-air aircraft ever to fly), or else haphazardly designed without use of refined mathematics.

This book is dedicated to the two masters of this art who first applied science and mathematics to this art, and brought us to where we are today - Professor Yasuaki Ninomiya, and Professor E.H Mathews. Without them, exceptional high performance paper airplanes would be unknown.

This book is also dedicated to you, the reader, and I hope you will find immense joy in flying the designs herein, and take inspiration from them !

TO ALL OUR FUTURE PIONEERS

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1. Introduction

ALWAYS BE VERY CAREFUL NOT TO HIT OTHER PEOPLE WITH YOUR PLANES AND DO NOT FLY THEM NEAR TO ROADS !

Paper Flight models and their flying performance can best be described in this way:

EPIC SPEED AND LONG DISTANCE !

Each model in this book has been designed to be able to fly **20+ meters when launched by hand** and then to be able to **fly 100+ meters when launched with a rubber band catapult**. This performance can be thought of as being able to fly across the width of a sports field when launched by hand, and along the length of the same field when catapult launched.

Paper Flight's models innovate in their construction, where the models are designed to be printed and constructed from ordinary 80 g/cm2 or 80gsm office photocopy paper. They can be balanced with their nose part sections glued onto cardboard, though this is an optional choice.

You won't need special tools - scissors and glue, and maybe some paperclips and self-adhesive rubber clay (such as Plasticine, Blutak and Prestik) are all that you will need.

The gliders feature catapult hooks made from paperclips cut and bent to shape. Turboprop and Jet models have the option of being built with and without engines for scale looks.

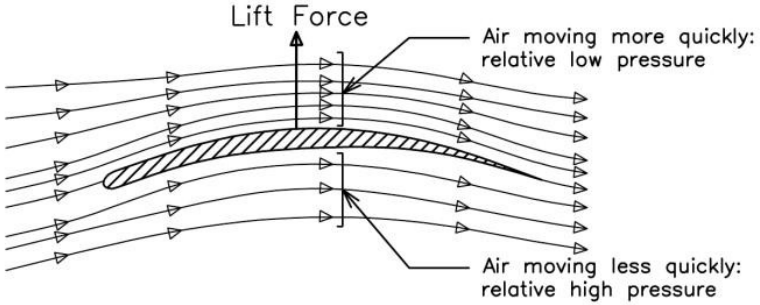
Some of the designs of airplanes in *Paper Flight* feature winglets, which not only improve their already good looks, and also help reduce drag to increase flight performance.

All the model airplanes in this volume were designed in CAD using aeronautical engineering design mathematics, and the process of design is published in the last chapter of this book.

2. Aerodynamics

Paper aircraft fly through the air by the same aerodynamic forces which allow full sized aircraft to fly and carry people from city to city, and country to country.

As air flows over the wing (seen here in cross section), the relative air speed above the wing is higher than that below it, and this difference in pressure produces the force that causes the airplane to fly - this force is known as **lift.**



Paper model airplanes are *gliders*, which are also known *sailplanes*. They do not have engines, and so the energy they use to fly with is initially the energy from the hand of the person throwing them, or the energy they received from a catapult or bungee launch.

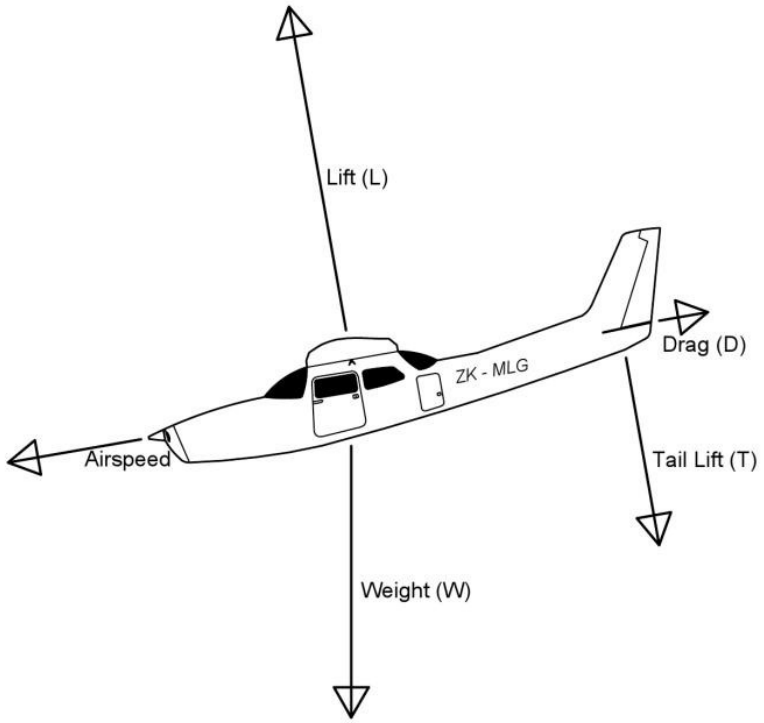
As they fly, their weight produces a downward acceleration. This happens as the gravity of the earth pulls the plane toward it. The lift force produced by the wings keeps the plane from hitting the ground immediately.

Then, the plane has forward speed. This is balanced by the force known as drag, where the small imperfections on the plane's skin and the shape of the plane itself turn air aside.

The tailplane of the model also produces a lift force, and this is directed downwards. The plane's flight is made stable by this, as it prevents the nose from pitching over, and the plane entering a dive.

Finally, the plane's tailfin keeps the plane stable as it flies along, and keeps its flightpath straight and true, like an arrow.

With forces of Lift, Weight, Drag, and Tail lift balanced, the model aircraft is capable of long, high speed flight.

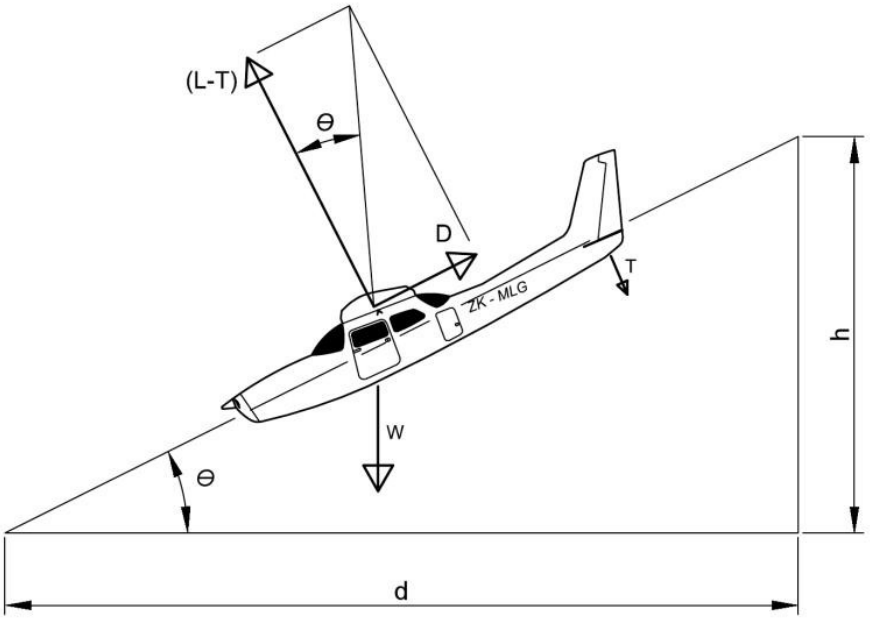


The next question is: how far can a paper model airplane fly?
The answer comes from working out what aerodynamic forces are applied to the model, and then working out the distance possible.

We will need some basic information to work this out:

- The height the model is launched from: h
- The angle of flight: Θ

Once we know these values, we can use them to work out the likely flight distance of our model airplane. In perfect conditions it is a very exact value. Real world conditions will give some variation - both **more** than and *less* than the perfect flight distance will happen for *any* flight - and this is what makes paper aircraft exciting!



Launch height and glide angle predict the performance of the glider, where all other factors remain constant - for instance, materials, design and construction.

For maximum flight distance, the following applies:

- The greater the launch height *h*, the farther the plane will fly.
- The smaller the glide angle Θ, the farther the plane will fly.

In aerodynamics, we can work this out with following formula:

l / d ratio = d / h

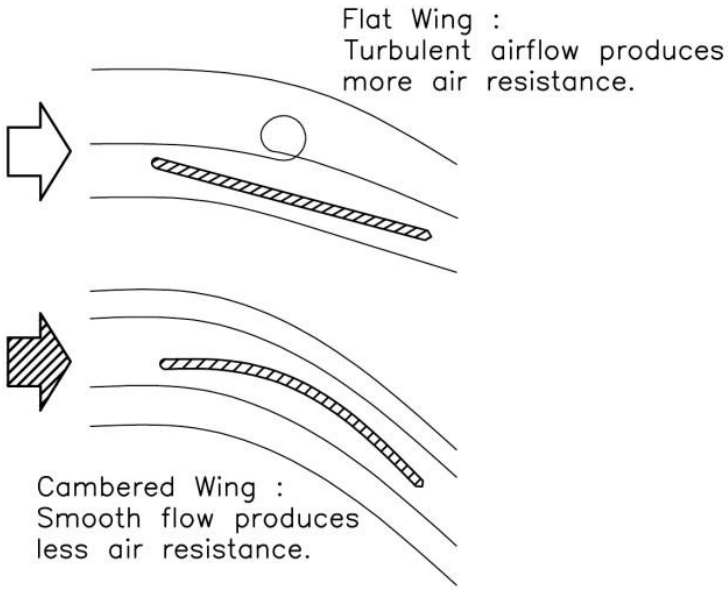
d / h = (L - T) / D

This is known as the *Lift to Drag Ratio* for the plane - also often referred to as the *l/d ratio* for short. **The higher the l/d ratio, the higher the performance of the plane.**
For example, the l/d ratio of a high performance sailplane is *very* high - often as great as 50, meaning that the sailplane can glide for 50 meters before it loses 1 meter of altitude.
Paper Flight gliders have an l/d ratio of between 20 and 40 depending on the design, and when well trimmed are able to fly epic long distances.

The biggest source of drag for paper model aircraft comes from anything that causes turbulence as the model passes through the air:

- Warped, bent or twisted wings, tail and fuselage
- Rough / damaged aircraft covering material
- Drag causing structures

A significant source of drag on even the smallest model aircraft are their wings. A flat wing generates far more drag than a cambered wing, as it generates turbulence, as can be seen here:

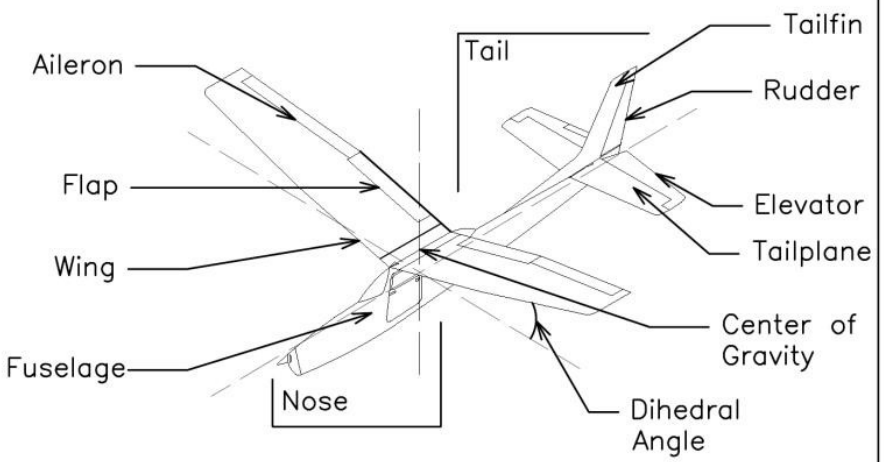


As you will see, the construction method used for the models in these books result in aircraft of high performance and lowest possible drag, so that they consistently fly with maximum speed and distance.

Once a wing is constructed, you can use your fingers to bend the wing into a cambered airfoil shape - and each model is provided with a Camber Gauge to allow you to make sure that the wing will produce maximum lift as it flies, for epic long distance flights every time.

3. Flight Trimming

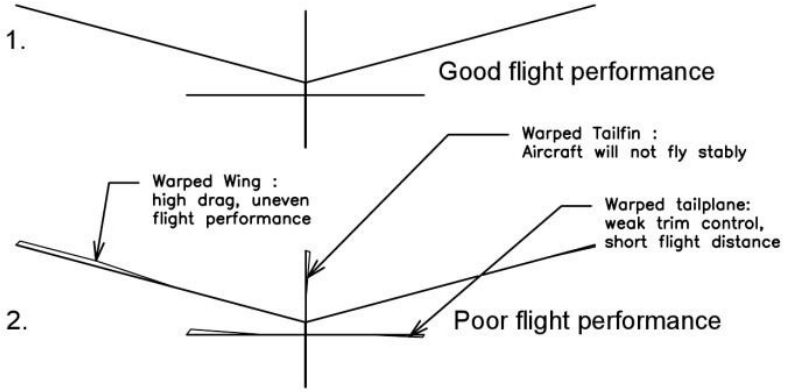
Flying model paper aircraft have the same parts as their full sized counterparts - however, they are much simpler in terms of construction. Here are the common parts of the paper aircraft :



For a paper aircraft to fly well, it needs to be **straight and true** - meaning that its flight surfaces are not bent or warped very badly. You can easily check your paper model for straightness by holding it with its nose pointing directly towards you.

If your model is straight and true, then it will look like picture 1.

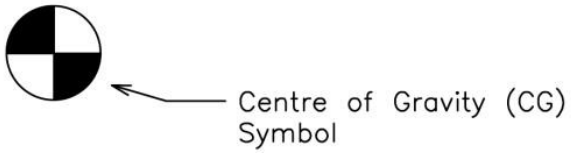
If it is not, then it will look more like picture 2. Using your fingers, it is possible to flatten the flying surfaces (wings, tailplane and and tailfin) so that a model that is warped can be straightened as much as possible before flight.


1.
Good flight performance
Warped Tailfin : Aircraft will not fly stably
Warped Wing : high drag, uneven flight performance
Warped tailplane: weak trim control, short flight distance
2.
Poor flight performance

For good flight performance, its also important to **launch** your model well.

The best way to launch a model is to hold it just behind the wing, and as close to the centre of gravity as possible :

On *Paper Flight* models, the *Center of Gravity* is marked with an 'A' symbol - you can see it under the center of the wing. In aerodynamics, the Center of Gravity is shortened to *CG* , and is also marked with a general symbol :

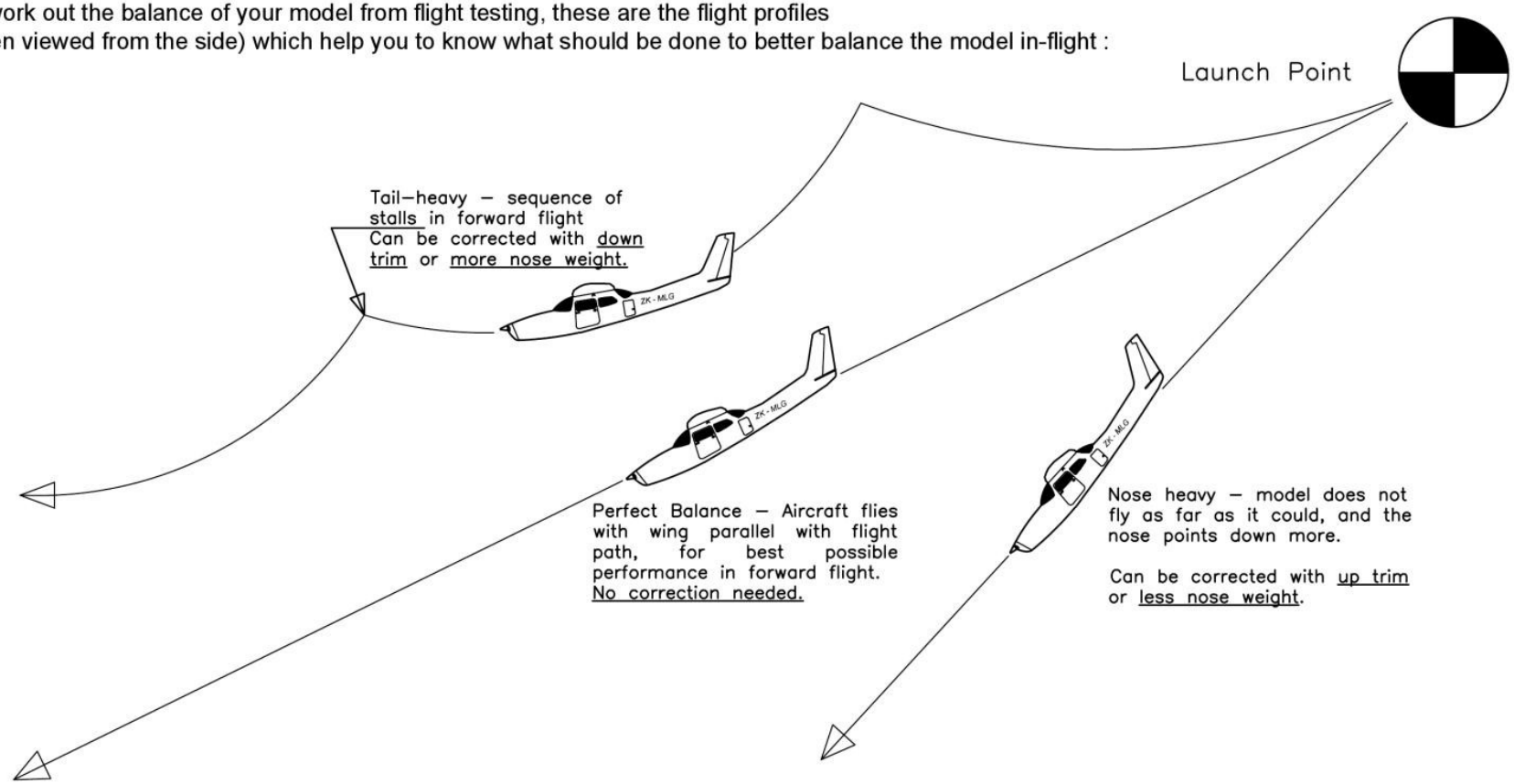


After the model aircraft is built, it is then important to flight test it. This done for three important reasons :

- Check that the model is balanced on its CG point correctly, and flying at the best possible performance.
- Check that the model is trimmed to fly straight and true - that it is not flying in a way not expected.
- Check that the glide angle is as small as possible for highest possible performance.

For CG balancing, its best to do this before flight testing, but no initial check is 100% foolproof - though *Paper Flight* models are **engineered** to this as easy as is possible.

To work out the balance of your model from flight testing, these are the flight profiles
(when viewed from the side) which help you to know what should be done to better balance the model in-flight :


Launch Point
Tail–heavy – sequence of stalls in forward flight
Can be corrected with down trim or more nose weight.
ZK - MLG
Perfect Balance – Aircraft flies with wing parallel with flight path, for best possible performance in forward flight.
No correction needed.
Nose heavy – model does not fly as far as it could, and the nose points down more.
Can be corrected with up trim or less nose weight.

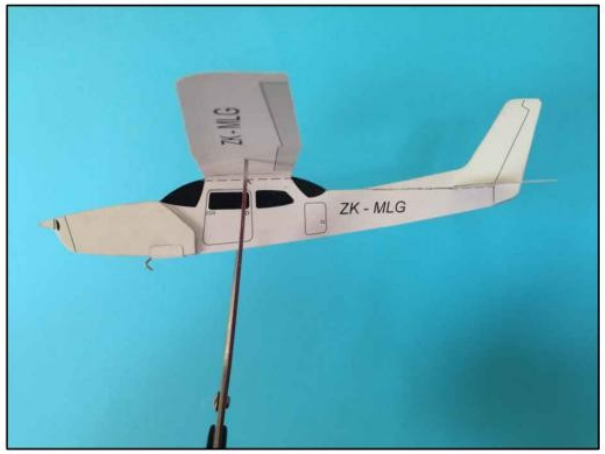
For the model to fly well, it needs to be balanced on the Center of Gravity, the CG (marked with the 'A' symbol).

To adjust the Balance on the CG point, you can use :

- Clay (Plasticine, Prestik, Blue Tack).
- Paper Clips.

Optionally, if the model is built using nose sections glued to cardboard, then ideally it should balance at the CG point, when on the tips of scissor blades :

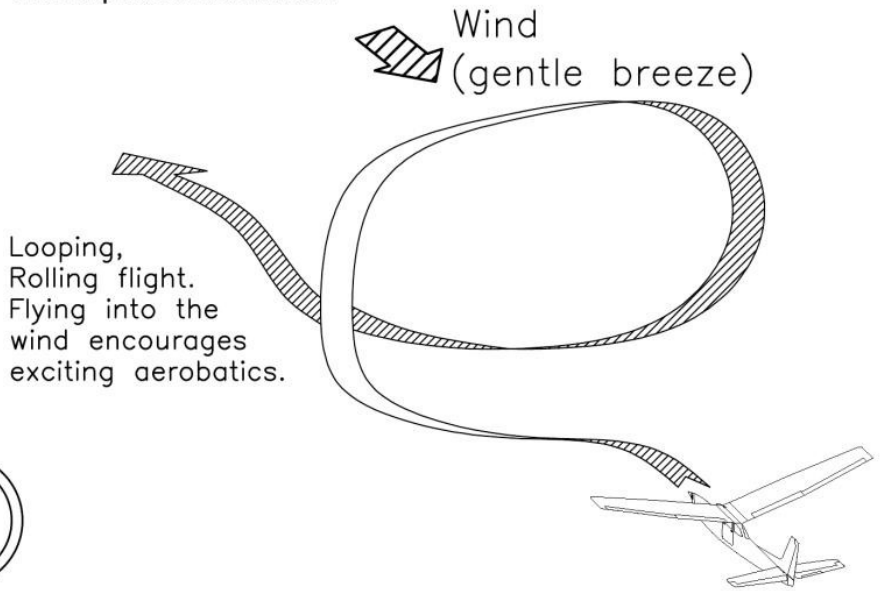
The scissor blades here are in line with the CG mark :



For low-winged models, the balance process is similar, The model is held inverted, and again should be balanced using the blades of a pair of scissors.

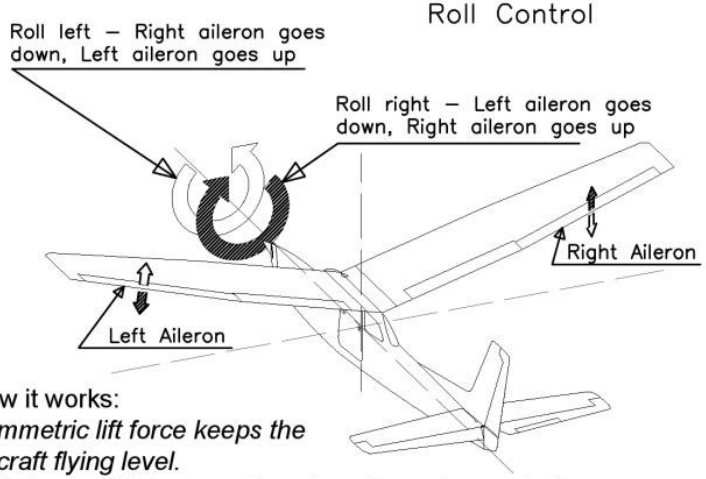
For launching the model, be as smooth as possible - the smoother the launch, the better it will fly.

With practice, as you become better at launching, is possible to put some energy into the launch with your hand, and the model is then able to not only fly farther, but depending on the angle used during launching, is even capable of aerobatics !



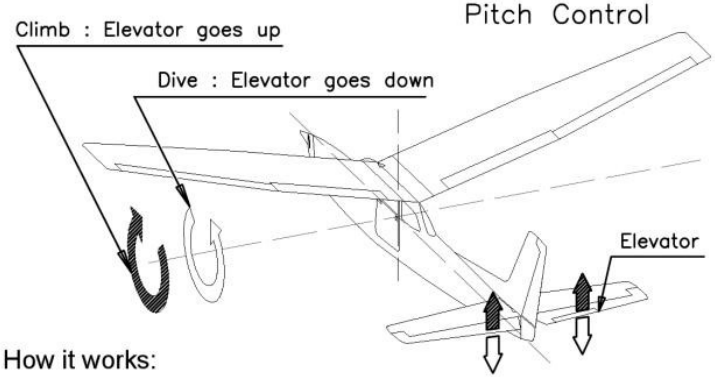
Flight controls of paper aircraft are the same as their full sized counterparts.

Roll Control


Roll left – Right aileron goes down, Left aileron goes up
Roll right – Left aileron goes down, Right aileron goes up
Right Aileron
Left Aileron

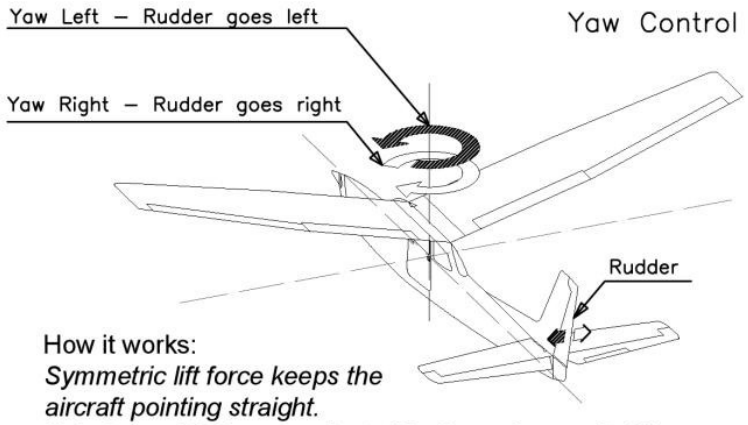
How it works:
Symmetric lift force keeps the aircraft flying level.
Unbalanced lift force on the wings (from changed wing cross section airfoil shape, increasing or decreasing lift) causes a **roll**.

Pitch Control



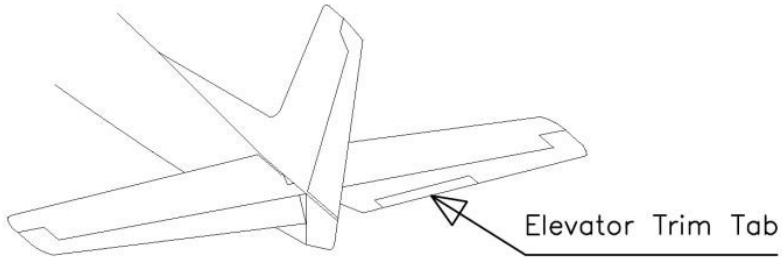
How it works:
Symmetric tail lift force keeps the aircraft flying level.
Unbalanced lift force on the tailplane (from changed tailplane cross section airfoil shape, increasing or decreasing lift) causes either a **climb or a dive**.

Yaw Control



How it works:
Symmetric lift force keeps the aircraft pointing straight.
Unbalanced lift force on the tailfin (from changed tailfin cross section airfoil shape, increasing or decreasing lift) causes a **yaw**.

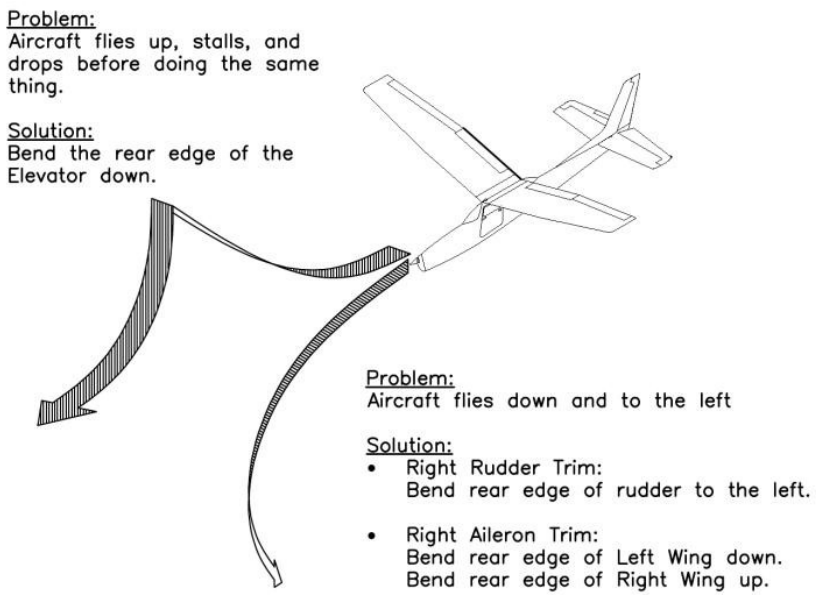
To *trim* a model aircraft, we can use the example of full sized aircraft. In flight, pilots trim their aircraft to fly level and to a course 'hands off' without constant manual correction. To do this, they make use of a *trim tab* , a small moving part of a larger control surface (such as the elevator, aileron and rudder). You can see an example of a trim tab here :



Controlling the dive and climbing of the aircraft can be very finely controlled with a trim tab, as the small changes in the up and down trim controls the rate of climb and descent. Similar controls are found on ailerons and rudders.

You can trim your model by BENDING the rear flight surface edge as if it is a TRIM TAB.

Trimming your model should be approached with care - small bends in the rear edge of the wing or tail surfaces - which are known as the *trailing edge* in aerodynamics - result in big changes in flight direction.


Problem:
Aircraft flies up, stalls, and drops before doing the same thing.
Solution:
Bend the rear edge of the Elevator down.
Problem:
Aircraft flies down and to the left
Solution:
• Right Rudder Trim:
Bend rear edge of rudder to the left.
• Right Aileron Trim:
Bend rear edge of Left Wing down.
Bend rear edge of Right Wing up.
• Elevator Trim:
Bend rear edge of Elevator up.

With care and practice, you will rapidly gain in experience in trimming your models.

Its possible to trim the models so well that they can fly indoors very effectively.

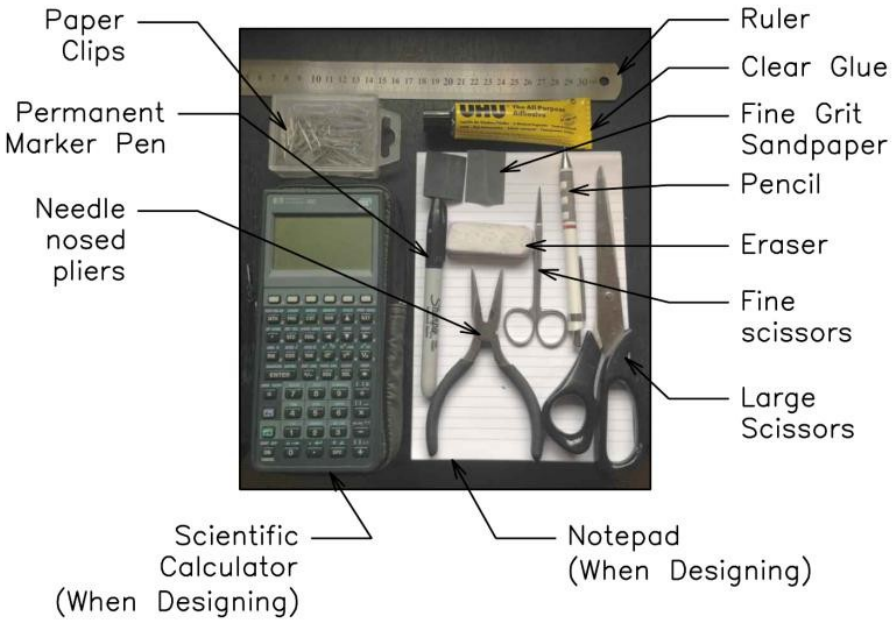
With perfect trim, and the best possible Lift-to-drag glide-slope, the performance of *Paper Flight* models is **AMAZING** !

- When hand launched, the models are easily able to fly 20 - 30 meter distances in still air.
- When catapult launched, the models are are easily able to fly 100 - 120 meter distances in still air.

The easiest way to think of this is : they can fly *across* a sports field with a hand launch, and *along its length* with a catapult launch !

4. Construction Guide

To build your models, you will need some computer equipment, and some basic stationery for construction.



When printing these designs from an electronic book format, you will need :

- A personal computer (PC) able to read eBook documents
- A printer able to print on A4-sized 80 gsm paper.

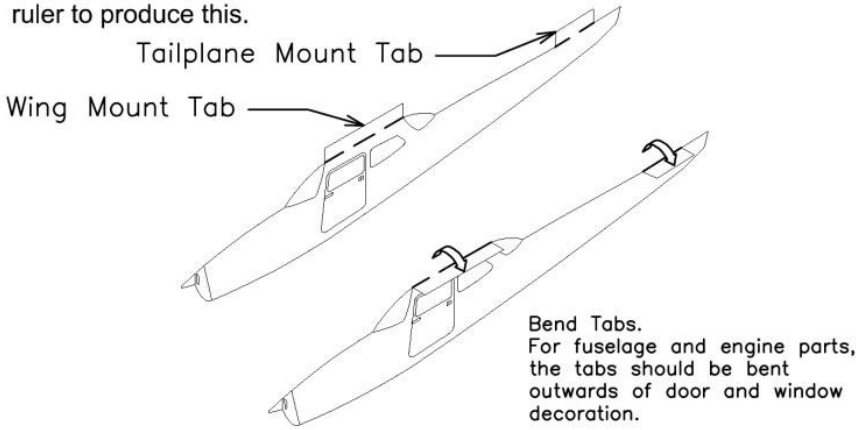
If printing these designs from a physical book, you will need :

- A photo-copy machine able to print on A4 80-gsm paper.

As well as paper, you may choose to use cardboard - the cardboard found in breakfast cereal and other home goods packages from the market or supermarket are very useful, and a great way to recycle the material.

For making a catapult, you will need a wooden pencil and rubber bands.

As you construct the models, first cut out the parts. The fuselage and engine model external parts have dashed lines on tabs - use these dashed lines to fold the tabs outwards. For a really straight fold, use a ruler to produce this.

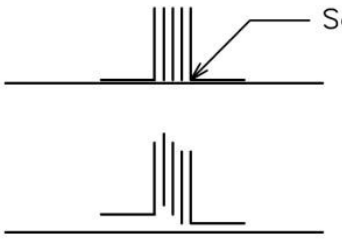

Tailplane Mount Tab
Wing Mount Tab
Bend Tabs.
For fuselage and engine parts, the tabs should be bent outwards of door and window decoration.

As you glue the parts together, spread the glue into a thin layers - this is to give the model maximum strength and good flying characteristics.

From experience, the best glues to use for assembly are :

- Uhu® All Purpose Glue.
- Sullivans® Craft Glue.
- Bostik® Clear Glue.

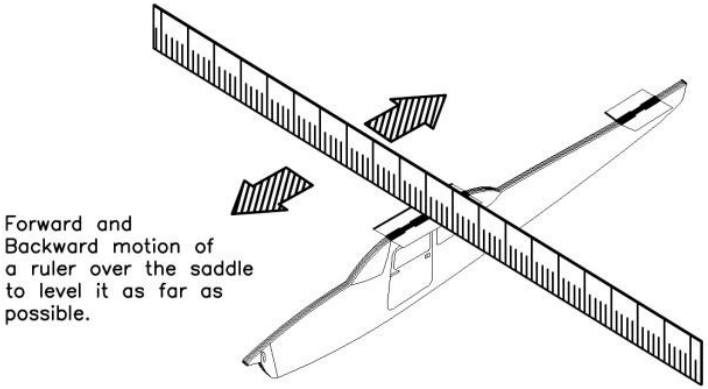
As far as possible, it is necessary to align the patterns for the wings, tail and particularly the fuselage of the model. This is so that when joining the wing and tailplane to the fuselage using the tabs (which is known as the *saddle joint*) the structure will be as strong as possible.



Good wing saddle joint, viewed from the front - the fuselage is aligned, and the joint is even. This makes the joint strong.

Poor wing saddle joint, viewed from the front - the fuselage is not aligned, and there are gaps between the saddle and the joint. This makes the junction *weak*, which is not good.

While it would be great if *every* model was perfect, the reality is that some small mistakes in part alignment do happen. With this in mind, it's possible to use a ruler to smooth the wing saddle as much as possible :



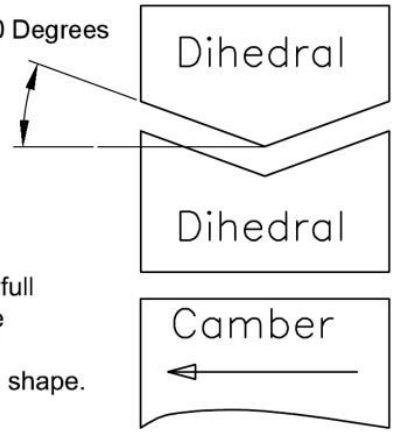
by pressing the ruler onto the saddle and moving it back and forth, this evens out the level as well as possible.

Other ways of doing this are to use a square of 400 grit sandpaper on the saddle after the fuselage has dried (with most craft glues this takes 20 - 30 minutes to form a strong bond).

In extreme cases, you can also use fine scissors.

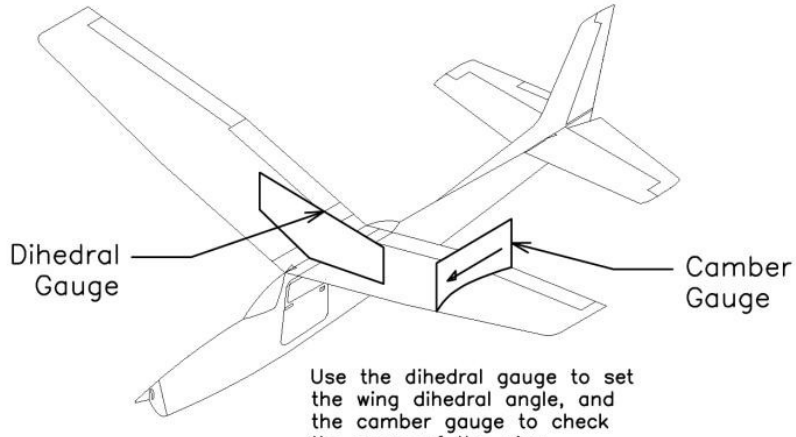
The models are provided with two tools for setting the wing for best performance:

- Dihedral Gauge
- Camber Gauge



These are cut out, and used to set the aerodynamics of the model's wing.

The camber shape is that of a very well known wing airfoil : the **CLARK Y** . This is a wing used in many model and full sized aircraft. *Paper Flight* wings are thin, but they are able to produce lift thanks to the properties of this airfoil shape.



Use the dihedral gauge to set the wing dihedral angle, and the camber gauge to check the curve of the wing.

Use your fingers to *curve* the wing into the cambered shape of the camber gauge. Without the wing camber, the wing will not generate much lift, and the aircraft will not fly well.

The dihedral of the wing produces stability for the model as it flies.

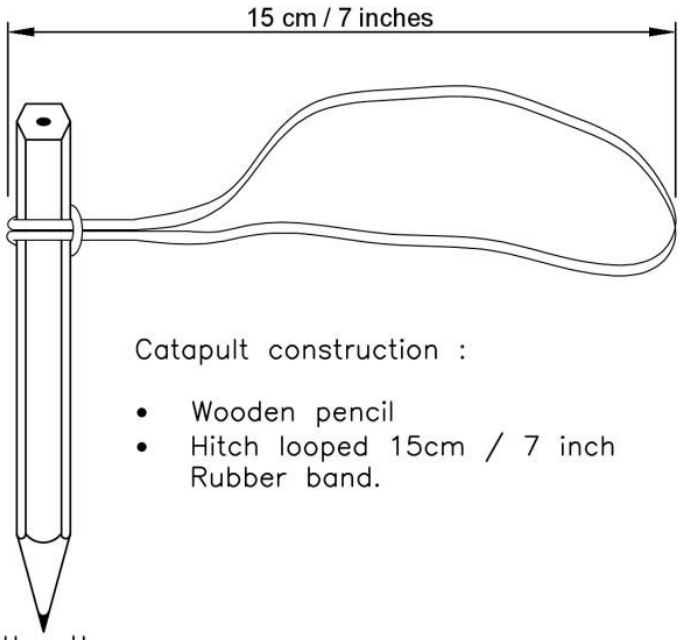
Low-winged models make use of the upwards pointing dihedral gauge, which provides the same function.

To strengthen the wing saddle, the models are provided with reinforcement mount strips, which you glue onto the wing saddle, and in turn increases the strength of the wing-fuselage junction as they dry.

There are thin slots in the fuselage for the **Catapult Hook**, which is made from a paper clip bent to shape, and cit, for mounting in the fuselage.

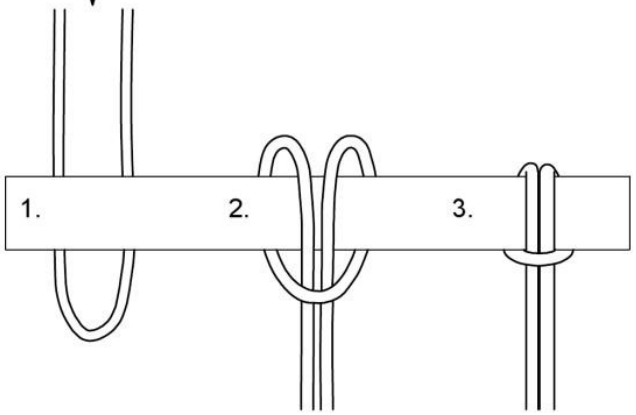
Its easy to make a **Catapult** from a wooden pencil and a 15 cm / 7 inch rubber band.

The rubber band can be secured using what is known as a **hitch loop**. Hitch loops are strong, and will allow your catapult to launch the model easily and well, for long distance flying.



Catapult construction :

- Wooden pencil
- Hitch looped 15cm / 7 inch Rubber band.



1. Loop 2. Hitch 3. Tighten.

5. The Models

Cessna 172RG Skyhawk

Country of origin : United States of America
Type : Single-engined private light aircraft, retractable undercarriage.
Engine : Continental O-360 Horizontally opposed 6 cylinder piston.
Performance : 226 km/h | 140 mp/h
Range : 1289 km / 696 nm at 12000 ft.
Weight : 1111kg
Crew : 1 pilot, 1 copilot / passenger, 2 passengers.
Notes : One of the most popular aircraft in the world today, the Cessna 172 Skyhawk can be seen flying in just about every country and continent. First flown in 1954, the modern Skyhawk has evolved over the years to its current form.

Today, Cessna (a Textron Company) continues to make new Skyhawks from its Wichita, Kansas factory, delivering them to proud pilots around the world.

The Skyhawk is operated as a flight school flight trainer for both civilian and miilitary pilots, and is beloved for its strength, quality and safety.

Pilatus PC-9

Country of origin : Switzerland
Type : Single-engined turboprop military flight trainer.
Engine : Pratt & Whitney Canada PT-6A Turboprop
Performance : 593 km/h max, 556 km/h cruise
Range : 1537 km / 830 nm
Weight : 2350kg
Crew : 1 student, 1 flight instructor.

Notes : The Pilatus PC-9 fist flew in 1976, and the model carries the registration of the first prototype. Developed sequentially from the P-3 piston engine flight trainer, which evolved into the PC-7 Turbo Trainer, the PC-9 incorporated all the most forward thinking ideas in military flight instruction - raised rear cockpit for instructor field of view ahead, and of the student pilot's actions; ejection seats, and a pressurised cockpit environment.

The PC-9 cannot carry armaments, the PC-7 Mark II sub model can by mating the PC-9 fuselage and engine to the hardpointed PC-7 wing.

The PC-9 also recently won the U.S. Air Force JPATS competition for the USAF intermediate trainer role, and is being manufactured under licence and with suitable modifications by Beechcraft (a Raytheon company).

Bombardier Dash-8 Q400

Country of origin : Canada
Type : Twin engine high wing turboprop airliner
Engines : Two Pratt & Whitney 123E turboprop engines
Performance : 532 km/h | 287 kts
Range : 1711 km / 924 nm
Weight : 19505 kg / 43000 lbs
Accomodation : 1 pilot, 1 copilot, 2 flight crew, 40 passengers

Notes : The Dash-8 (which began life as the DeHavilland Canada DHC-8 - hence, *Dash-8*) first flew in 1978, and has been the subject of development since then by DeHavilland Canada, and then by Bombardier, the current manufacturer.

Found flying all over the world, the Dash-8 is a comfortable high speed turboprop short-medium range airliner, which retains excellent STOL (**S**hort **T**ake **O**ff and **L**anding) capability for flying out of limited runways, and yet still providing the highest quality in flight comfort for passengers.

The current production version is the Q400, which has large 6 bladed propellers for low in-flight noise, for highest possible efficiency.

Rockwell Aero Commander 840

Country of origin : United States of America
Type : Twin turboprop private light aircraft
Engines : Two Garrett TEP331-10-511K Turboprop engines
Performance : 326 km/h | 176 kts
Range : 1735 km / 936 nm
Weight : 3062 kg / 6750 lbs
Crew : 1 pilot, 1 copilot / passenger, up to 6 passengers.

Notes : The design team of the Rockwell Aero Commander based their concept on the high performance WWII Douglas A-26 Invader, which they re-imagined as a high wing executive and utility transport aircraft.

Over the years since it flew in 1956, the Aero Commander and Jetprop / Jet Commander as it became known, evolved into a beautiful high speed turboprop transport from its humbler beginnings with piston engines, though it has always retained high performance.

The late legendary WWII fighter ace R.A. 'Bob' Hoover made the Aero Commander world-famous for his regular air-show performances in which he flew full aerobatic routines; first with only one engine, and then with no power at all - flying the Aero Commander as a sailplane, with both engines off and propellers feathered!

The paper model Aero Commander shares the RA500 registration with 'Bob' Hoover's famous aircraft.

Beechcraft Super KingAir B200

Country of origin : United States of America
Type : Twin engined turboprop executive transport aircraft
Engines : Two Pratt & Whitney Canada PT6A-25 turboprop engines
Performance : 574 km/h | 310 kts
Range : 3185 km / 1720 nm
Weight : 4005 kg / 8830 lbs
Crew : 1 pilot, 1 copilot, up to 12 passengers.

Notes : The Beechcraft Super KingAir B200 remains one of the fastest and most capable turboprop aircraft in the world today. Sleek and fast, its performance is only exceeded by higher speed private business-jet aircraft, and by a margin which is not very wide.

It has given rise to the Beech 1900 airliner family, with which it shares a great deal of commonality in terms of design lineage.

In production for many years, it is used widely by both private organisations and air forces where its duties range from humanitarian missions and transport missions to ELINT (Electronic Intelligence) and coastal ocean patrol.

Grumman Gulfstream G550

Country of origin : United States of America
Type : Twin engined long-range private business transport jet.
Engines : Two Rolls-Royce BR725 high bypass turbofans
Performance : Mach 0.925 / 982 km/h
Range : 12960 km / 7000 nm
Weight : 45200 kg / 99600 lbs
Crew : 1 pilot, 1 copilot, up to 14 passengers

Notes : The Grumman Gulfstream G550 is the descendant of a distinguished line of private transport aircraft, very popular around the world today.

The G550 has intercontinental range, able to easily fly across the Atlantic Ocean departing from Europe, and in suitable conditions fly all the way to California in a single flight !

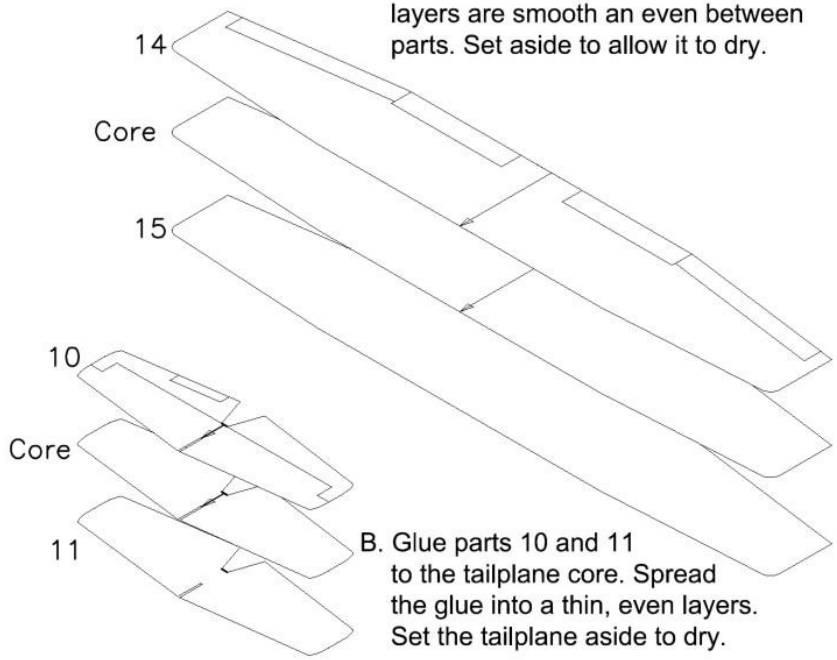
As a business jet, and unlike the majority of its competitors, it is *huge*, literally as large as a Boeing 737 medium range jet airliner !

With long slender wings, the Gulfstream flies quickly and stably, cutting through the air at high speed. It is fast, powerful, and very graceful.

6. ASSEMBLY

CESSNA 172RG Skyhawk

A. Glue wing parts 14 and 15 to the wing core. Make sure that the glue layers are smooth an even between parts. Set aside to allow it to dry.

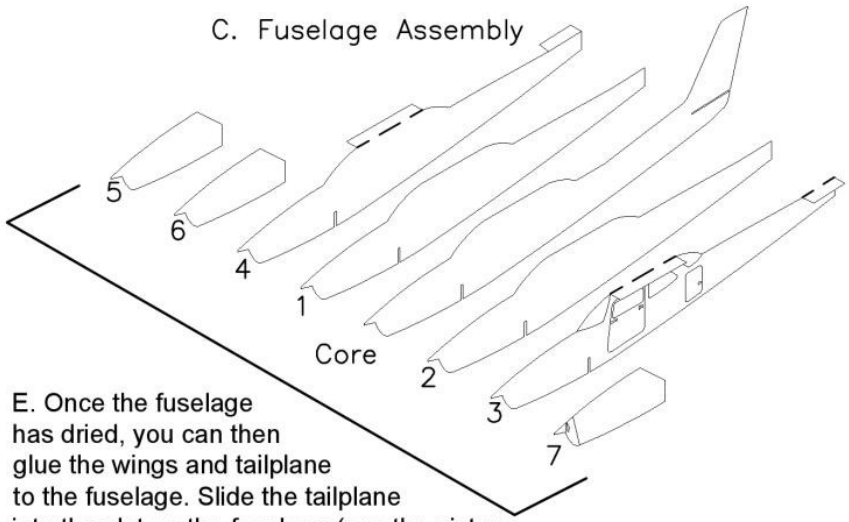


B. Glue parts 10 and 11 to the tailplane core. Spread the glue into a thin, even layers. Set the tailplane aside to dry.

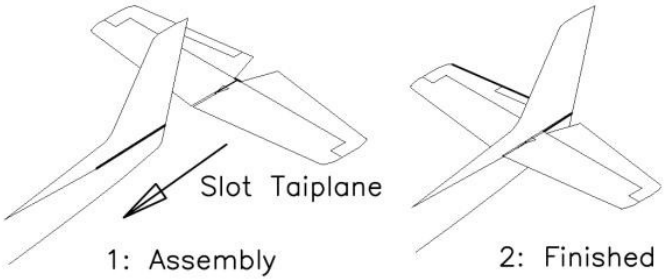
C. Cut out and assemble the fuselage parts.
Make sure that you bend the mounting tabs outward. Glue the parts together, using thin even glue layers covering the entire surface.

D. Allow the fuselage to dry, before doing additional assembly. Use this time to make part 18, the catapult hook, from a paper clip. You will need a pair of needle nose pliers to do this - if you have never done this before, ask for help from a responsible or experienced person.

C. Fuselage Assembly



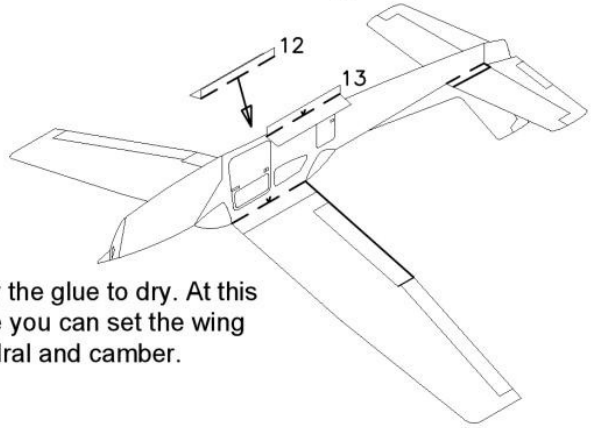
E. Once the fuselage has dried, you can then glue the wings and tailplane to the fuselage. Slide the tailplane into the slot on the fuselage (see the picture below to see how the model should look)



1: Assembly

2: Finished

F. Reinforce the underside of the wing with parts 12 and 13:



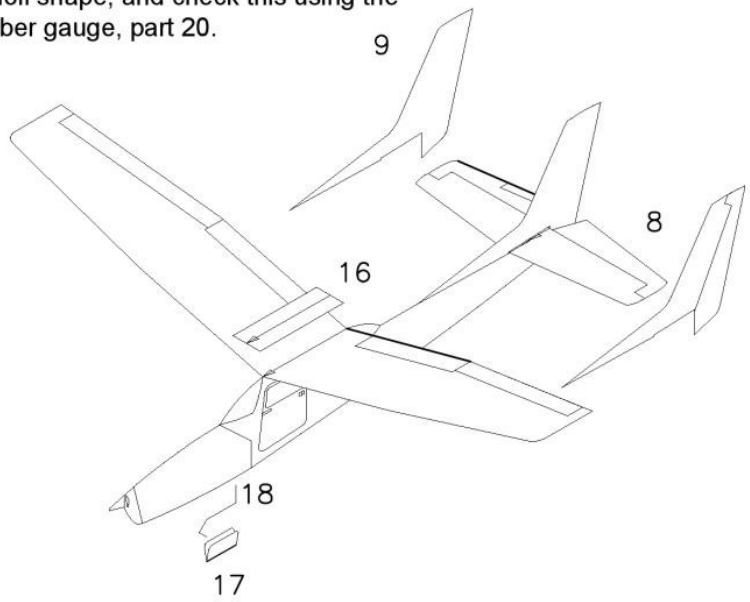
Allow the glue to dry. At this stage you can set the wing dihedral and camber.

G. Completion of assembly:

Glue the tail fin outer parts 8 and 9 to the central tail fin - this is to provide strength to the tail. Glue wing saddle reinforcement part 16 to the wing saddle, facing forwards as illustrated.

Glue catapult hook, part 18, into the fuselage slot cut out earlier. Reinforce the catapult hook using part 17, folded and glued into place.

Set the wing dihedral using part 19, and use a ruler to make sure that the bend is even and straight. Bend the wing with your fingers into an aerofoil shape, and check this using the Camber gauge, part 20.



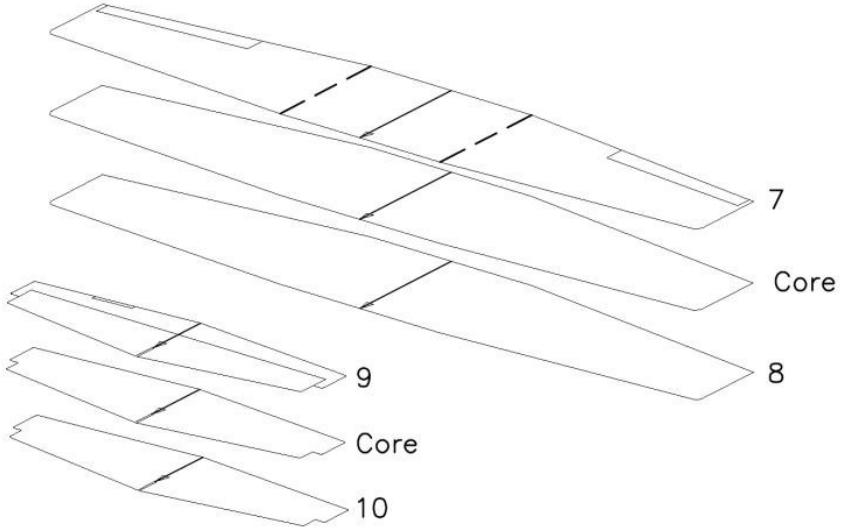
The model should be balanced on the C.G. 'A' Mark, making use of Plasticine, Prestik/Blu Tack or paper clips.

For a clean appearance, you can also glue nose parts 5, 6 and 7 to cardboard before assembly, to balance the model.

To trim the model, make use of the trimming guide in Chapter 3.

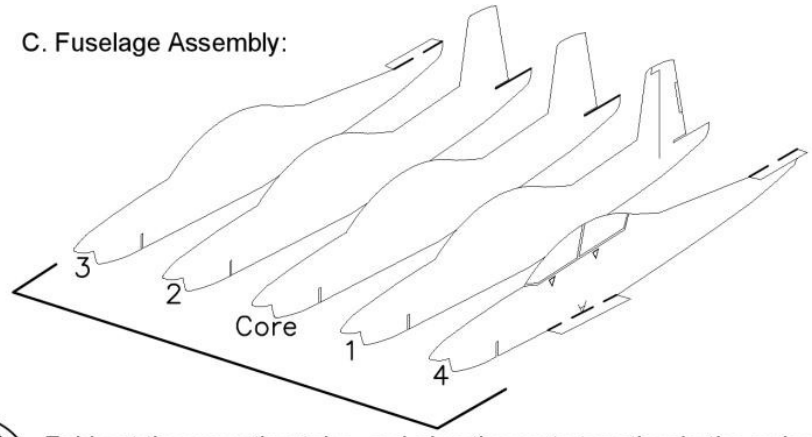
Pilatus PC-9

A. Glue wing part 7, core and 8 together. Spread the glue into a thin even layer between parts when doing this. Set the wing aside, allow it to dry.



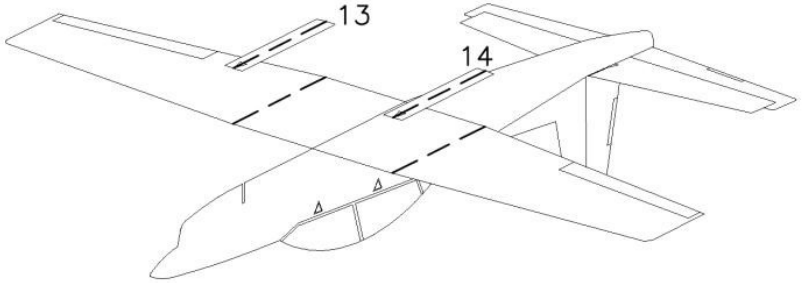
B. Glue tailplane parts 9 , core and 10 together. pread the glue into thin, even layers between parts when doing this. Set the tailplane aside, and allow to dry.

C. Fuselage Assembly:



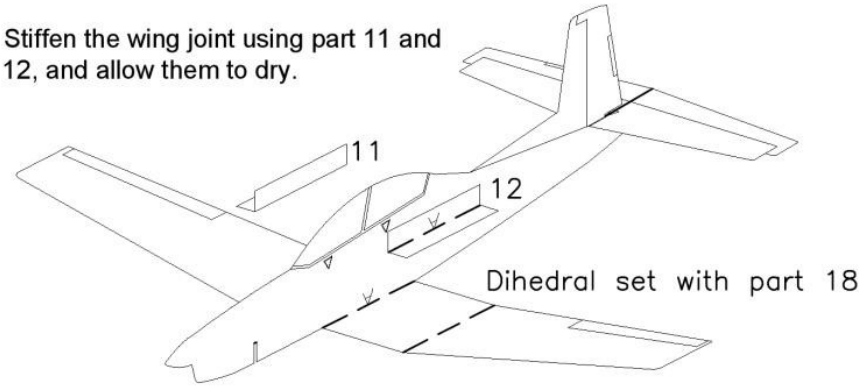
Fold out the mounting tabs, and glue the parts together in the order illustrated. Spread the glue into an even thin layers between parts. Set the fuselage aside and allow it to dry.

D. Assembly of the model:
Glue the wing and tailplane to the fuselage using the mounting tabs.
To stiffen the wing dihedral, glue parts 13 and 14 to the wing underside.

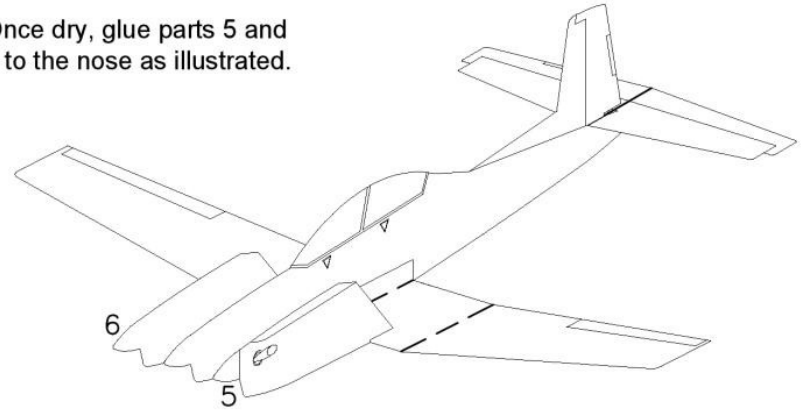


Once dry, set the wing dihedral using part 18, and set the wing camber using part 17 by curving the wing to shape with your fingers.

Stiffen the wing joint using part 11 and 12, and allow them to dry.

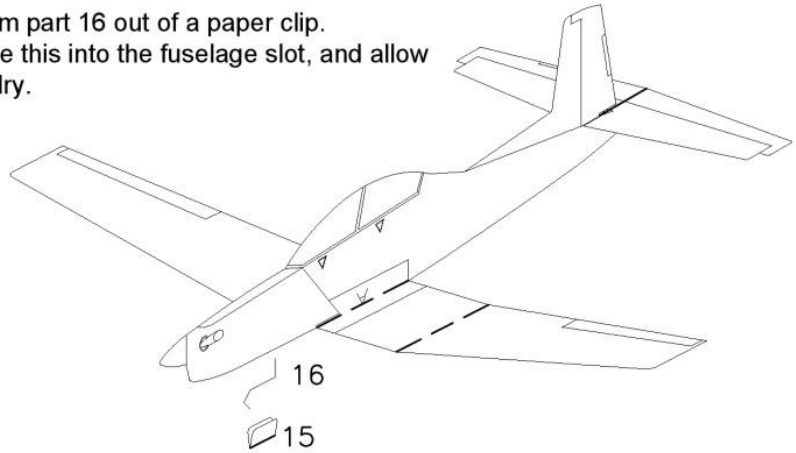


Once dry, glue parts 5 and 6 to the nose as illustrated.



E. Completion of assembly:

Form part 16 out of a paper clip.
Glue this into the fuselage slot, and allow to dry.



Glue part 15 over the catapult hook. After all is dry, the assembly is complete.

The model should then be balanced on its C.G. (the 'A' mark), making use of Plasticine, Prestik/Blu Tack, or else paper clips.

For a clean appearance to glue nose parts 5 and 6 to balance the model on its C.G.

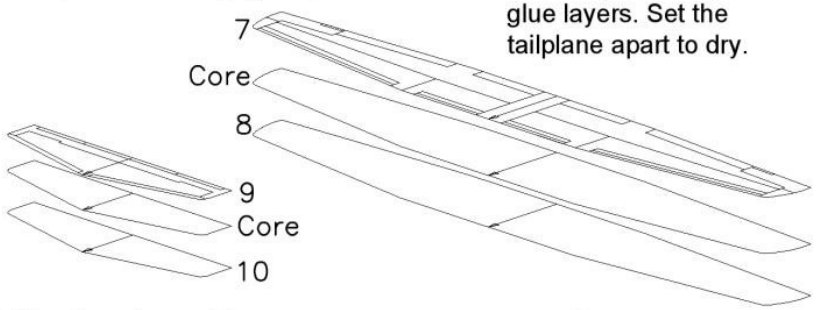
To trim the model, make use of the trimming guide in Chapter 3.

The PC-9 is very aerobatic like its full sized counterpart, and is responsive to wind conditions when launched, easily looping and rolling in a gentle breeze.

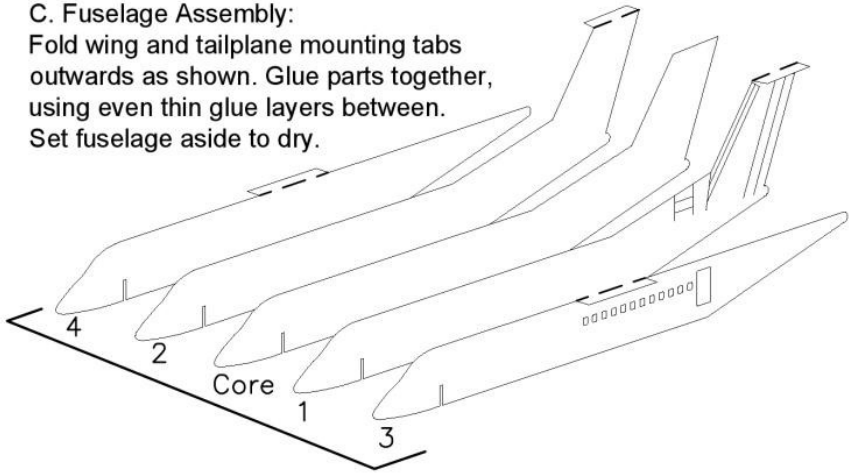
Bombardier Dash-8 Q400

A. Wing assembly glue parts 7 and 8 to the core. Spread the glue into thin, even layers between parts. Set the wing aside to dry.

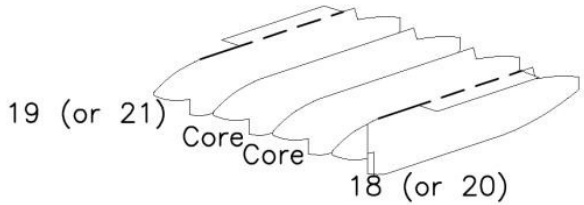
B. Tailplane assembly: glue parts 9 and 10 to the core, with thin, even glue layers. Set the tailplane apart to dry.



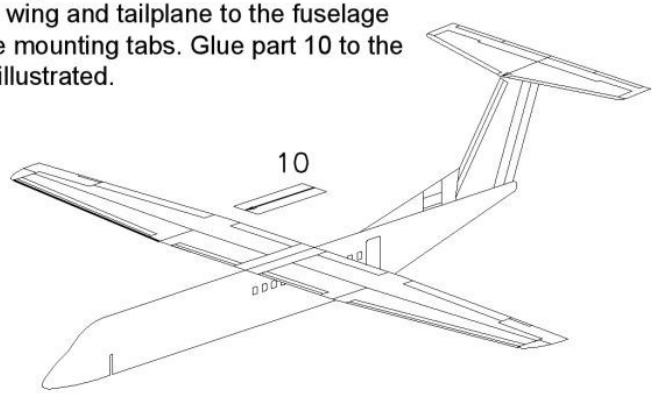
C. Fuselage Assembly:
Fold wing and tailplane mounting tabs outwards as shown. Glue parts together, using even thin glue layers between. Set fuselage aside to dry.



D. Engines (optional): Fold out the mounting tabs, and glue together as shown. Spread the glue into a thin, even layers between parts. Set aside to dry.

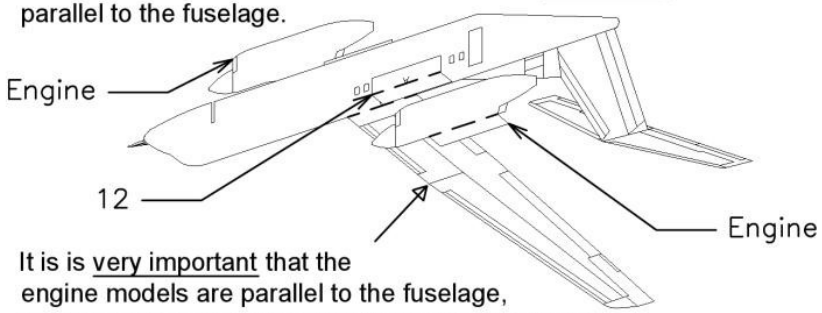


E. Assembly:
Glue the wing and tailplane to the fuselage using the mounting tabs. Glue part 10 to the wing as illustrated.



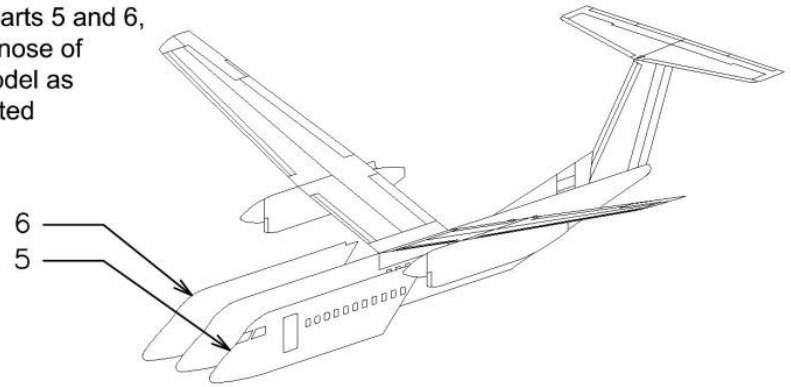
Next, set the wing dihedral using part 17. Also gently bend the wing to the correct cambered airfoil shape, using part 16 as the camber pattern.

Glue the wing dihedral braces (parts 12 and 13) to the wing roots. When attaching the engines to the fuselage, make sure that they are parallel to the fuselage.



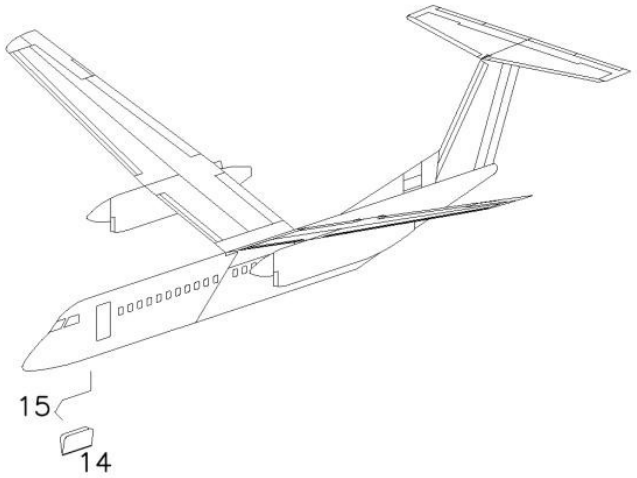
It is is very important that the engine models are parallel to the fuselage, as if they are not, the model will need a great deal of trimming, and have lower performance.

Glue parts 5 and 6, to the nose of the model as illustrated



Bend part 15 out of a paper clip using needle-nosed pliers, to make the catapult hook. If unsure of how to do this, get the help of an experienced or responsible person.

Glue part 15 into the fuselage, and use part 14 to hold the hook in place.



The model should be balanced on its C.G. (the 'A' mark), making use of Plasticine, Prestik/Blu Tack, or else a paper clip.

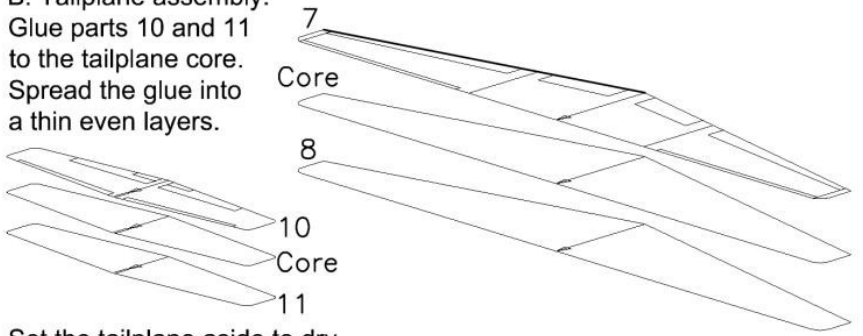
For a clean appearance, gluing either part 5 or 6 can be glued to cardboard, and the model balanced on its C.G.

To trim the model, make use of the trimming guide in Chapter 3.

Aero Commander 840

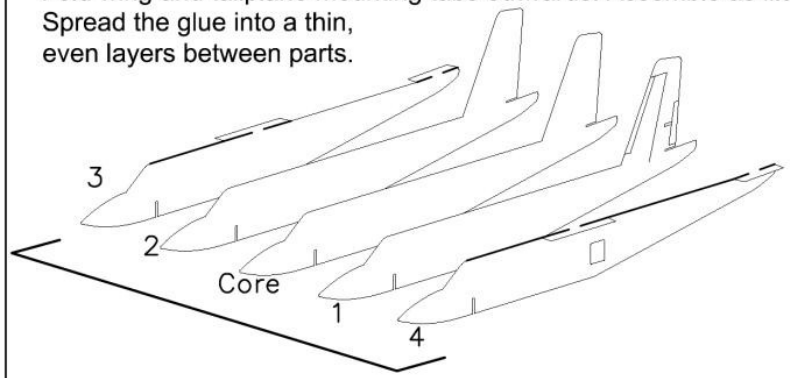
A. Wing Assembly Glue parts 7 and 8 to the wing core. Spread the glue into a thin even layer to do this. Set the wing aside to dry.

B. Tailplane assembly:
Glue parts 10 and 11 to the tailplane core. Spread the glue into a thin even layers.



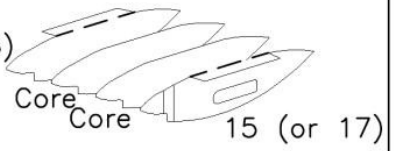
Set the tailplane aside to dry.

C. Fuselage construction.
Fold wing and tailplane mounting tabs outwards. Assemble as illustrated. Spread the glue into a thin, even layers between parts.



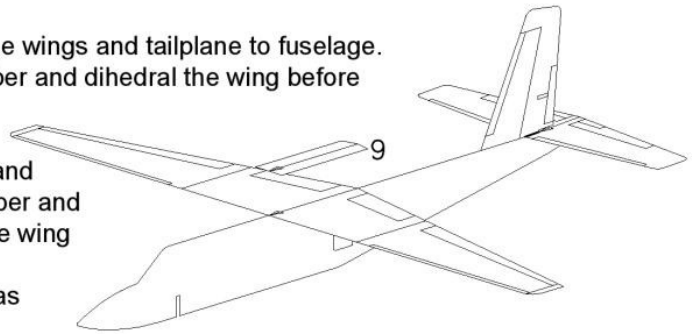
Set the fuselage apart, and allow to dry.

E. Engine Models (optional)
Fold out mounting tabs.
Spread glue into thin, even layers between parts when assembling.
Set the engine models aside to dry.



F . Assembly:

Mount and glue wings and tailplane to fuselage. You can camber and dihedral the wing before mounting
if you prefer - Use parts 20 and 21 to set camber and dihedral for the wing

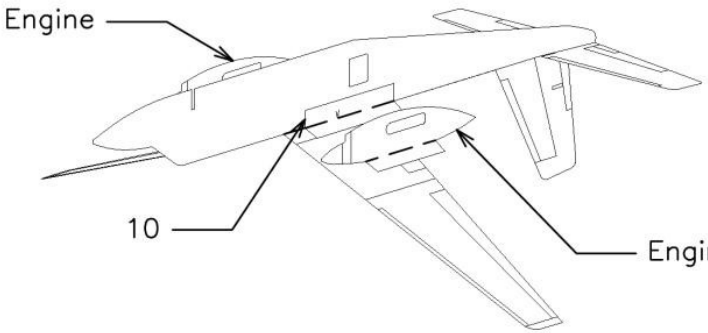


Attach part 9 as illustrated.

Once the dihedral is set with part 20, its then necessary to strengthen the wing on the fuselage - use parts 12 and 13 to do so, aligning them so that the wing C.G. mark 'A' is aligned with that of the fuselage.

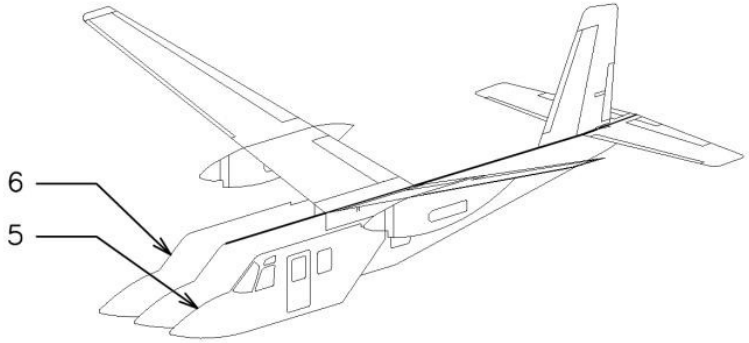
Curve the the wing into its airfoil shape with your fingers and using the camber gauge (part 21) before attaching the engine models.

The dry engine models can be glued to the wing at this stage if desired.



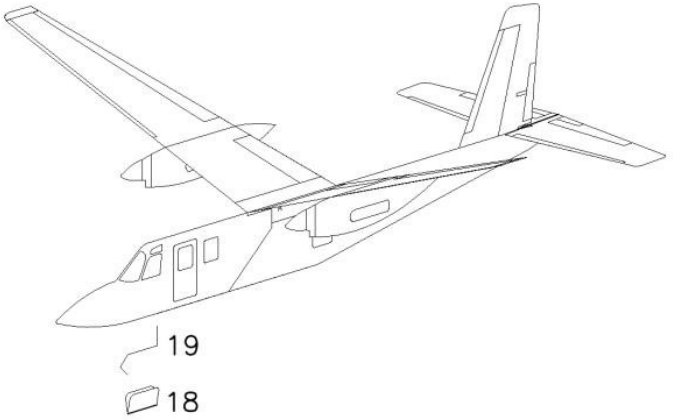
It is very important that the engine models are parallel with the fuselage for minimum drag, and so that the model will not need a lot of trimming. Use the lines on the wing to align the engines.

Once the engine models, and the underwing braces are dry and set, its then possible to glue the nose sections (parts 5 and 6) into place.



To balance the model on its C.G. 'A' mark using Plasticine, Prestik/Blu Tack, or paper clips.
For a clean appearance, glue parts 5 and 6 to cardboard for balancing the model on its C.G.

Make the catapult hook, part 19 out of a paper clip using needle-nosed pliers.



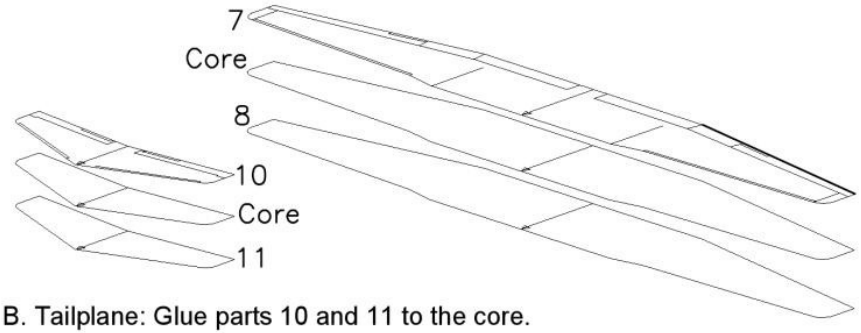
If unsure of how to do this, get the help of a responsible or experienced person. Glue the hook into the fuselage slot, and secure using part 18 as illustrated

To trim the model, make use of the trimming guide found in Chapter 3.

Like its full size counterpart, the Aero Commander is very aerobatic, and easily loops and rolls when flown in a gentle breeze.

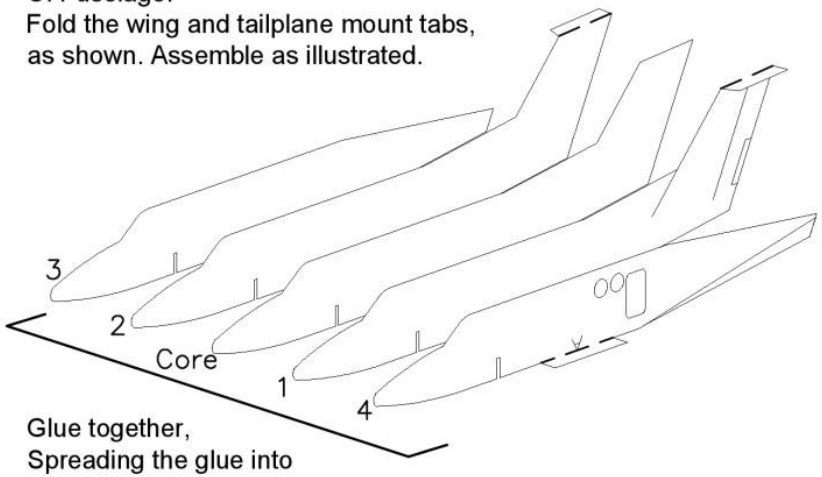
Beechcraft Super KingAir B200

A. Wing: Glue parts 7 and 8 to the wing core. Spread the glue into thin, even layers between parts. Set the wing aside and allow it to dry.



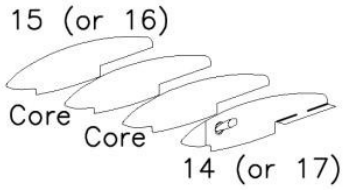
B. Tailplane: Glue parts 10 and 11 to the core.
Spread the glue into thin even layers between parts. Set aside to dry.

C. Fuselage:
Fold the wing and tailplane mount tabs, as shown. Assemble as illustrated.



Glue together,
Spreading the glue into
thin, even layers between parts. Set the fuselage aside to dry.

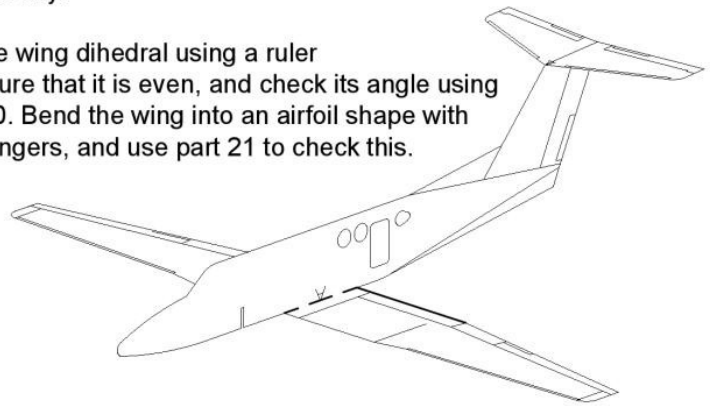
D. Engines (optional)
Fold the mount tabs as shown.
Glue together, spreading the glue into thin, even layers between parts.
Set the engines aside to dry.



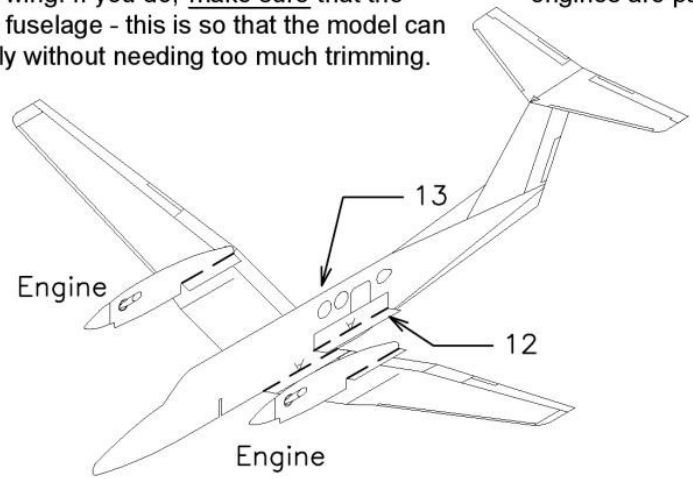
E. Assembly:

Glue the wing and tailplane to the fuselage as shown in the illustration below. Spread the glue into even thin layers between parts, and allow the joints to dry.

Set the wing dihedral using a ruler to ensure that it is even, and check its angle using part 20. Bend the wing into an airfoil shape with your fingers, and use part 21 to check this.

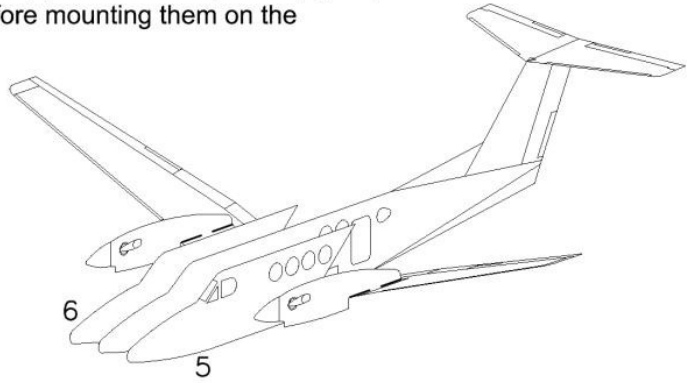


Once dry, its then possible to mount the model engines to the wing. If you do, make sure that the engines are parallel to the fuselage - this is so that the model can then fly without needing too much trimming.

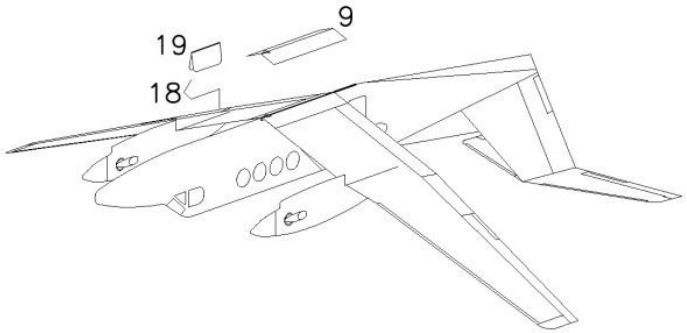


To reinforce the wing joint, glue parts 12 and 13 as illustrated to increase strength. Spread the glue into thin, even layers while doing so. Allow the assembly to dry.

For C.G. Balancing on the 'A' mark, make use of Plasticine, Prestik/Blu Tack, or paperclips .
For a clean finish, you can also optionally glue parts 5 and 6 to cardboard. before mounting them on the fuselage.



Make the catapult hook (part 18) from a paper clip using needle-nosed pliers. If unsure of how to do this, get the help of a responsible or experienced person.



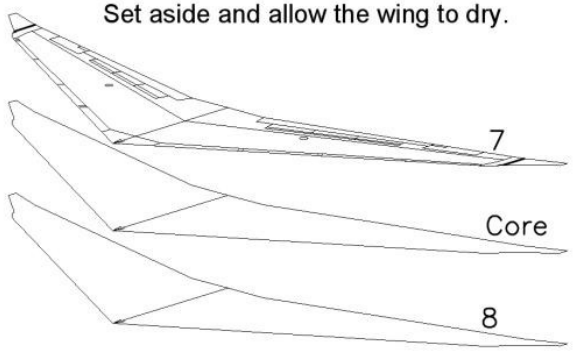
Strengthen the wing with part 9, as illustrated.

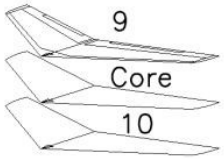
Glue the hook into the slot,
and secure the catapult hook with part 19, and glue together.

To trim the model, make use of the trimming guide in Chapter 3.

Grumman Gulfstream G550

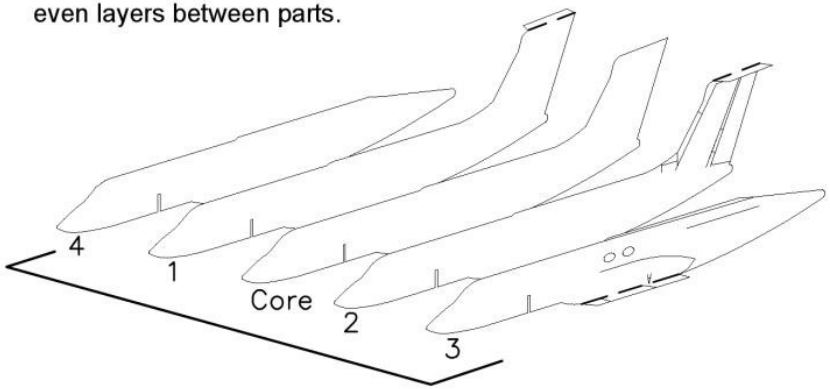
A. Wing Assembly: Glue parts 7 & 8 to the the core. Spread the glue into thin, even layers between parts, for the strongest possible bond.
Set aside and allow the wing to dry.





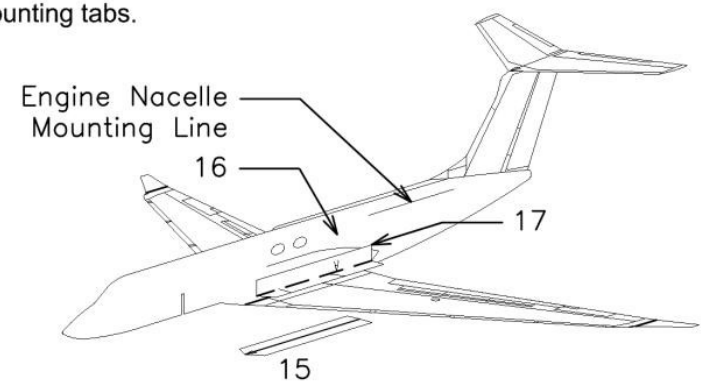
B. Tailplane: Glue parts 9 and 10 to core. Spread the glue into thin, even layers between parts for the strongest possible bond. Set aside the tailplane to dry.

C. Fuselage:
Bend the wing and tailplane mounting tabs outwards as illustrated.
Glue the parts together in the order illustrated. Spread the glue into thin, even layers between parts.



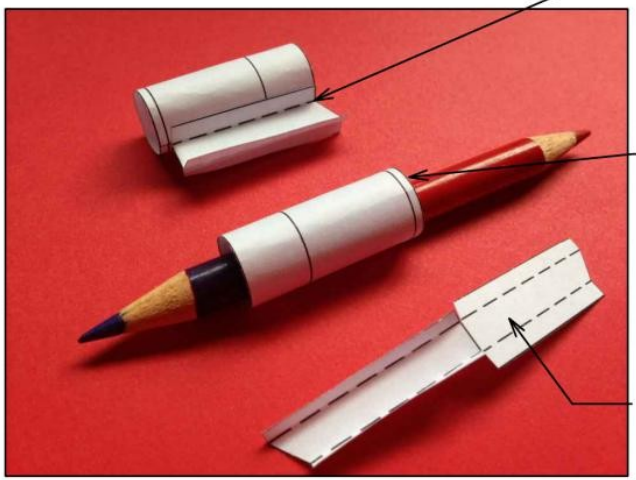
Set the assembled fuselage apart and allow to dry.

E. Intermediate Assembly:
Mount the wings and tailplane to the fuselage, by glueing them to their mounting tabs.



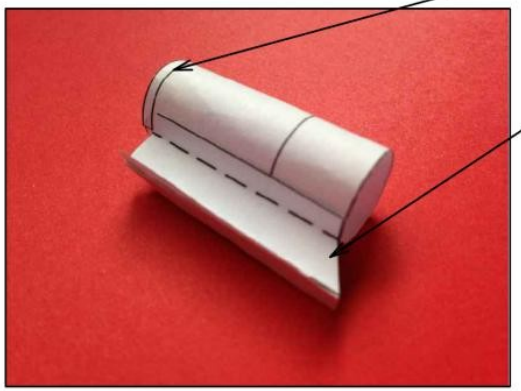
Glue the wing root strengthening strips parts 16 and 17 , and strengthen the wing root with part 15 as illustrated above.

E. Engine Nacelles (Optional feature):
Assembly of the engines is in the form of a rolled tube representing the turbofans, and two pylons.
Use a round rod (like a pencil) to roll parts 13 and 14. Use the glue tab to complete their assembly.

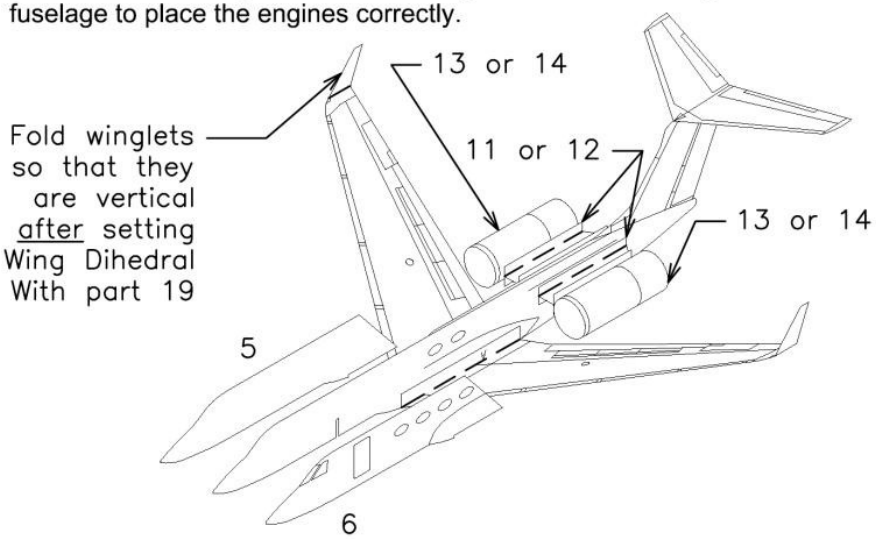


Fold parts 11 & 12, and glue as illustrated, with the mounting tabs folded so as to assemble the model engines.

The finished engine assembly looks like this:


Mount engine on pylon forward of this line, as illustrated
Glue the engine to the pylon in the orientation illustrated, for lowest drag

In the diagram below, you can see an alternate method of assembling the engine nacelles, from rolled parts 13 & 14, and parts 11 & 12, all of which are interchangeable. Use the engine nacelle mounting line on the fuselage to place the engines correctly.



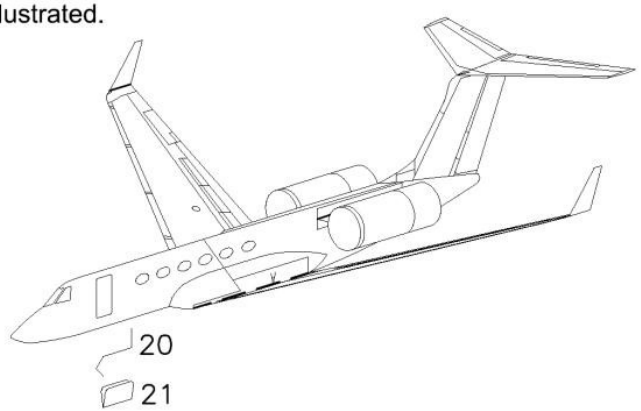
F. Final Assembly:
For C.G. Balancing on the 'A' Mark, use Prestik/Blu Tack, or paper clips.

For a clean appearance, you can also glue either part 5 or 6 to cardboard before gluing to the fuselage; Alternately, both parts 5 and 6 can be glued to thinner card before being glued to the fuselage. From experience, the model will balance perfectly.

Use the dihedral gauge (part 19) to set the wing dihedral. Fold the winglets so that they are vertical - see the diagram below for the correct appearance. Bend the wing with your fingers so that it has a curved aerofoil, and check this shape using the camber gauge (part 18).

Make the catapult hook (part 20) from a paper clip, using a pair of needle nosed pliers. If unsure of how to do this, get the help of a responsible person, or an experienced person to help you to do this.

Glue the catapult hook into the fuselage slot. Secure the hook using part 21 as illustrated.



It is very important to make sure that the engine nacelles are well aligned, though any effect of misalignment on flight can be corrected by trimming.

To trim the model, make use of the trimming guide in Chapter 3.

The model Grumman Gulfstream G550 has by far the fastest speed of the models in this book, its swept wing gives it arrow-like flight.

The Plans

The plans of the paper models can be found on the pages following this one.

When printing them from a PDF document, make use of A4 80 gsm photocopy / printer paper. If using a printed book, photocopy them on the same paper type.

The models were designed with this paper type in mind, to make them easy to produce and assemble - there is almost no place in the world today where this type of paper is not in widespread use.

A major part of the entertainment and enjoyment of any type of model aircraft comes fro its construction, as well as from its flying. The models in this book are designed to give both - they are easy to build, and then they have epic flight performance !

To experience these epic flights for yourself, it is very important that the models be well built as far as you possibly can, and then to flight trim them so that they fly straight and true.

Paper Flight – Cessna 172RG Skyhawk
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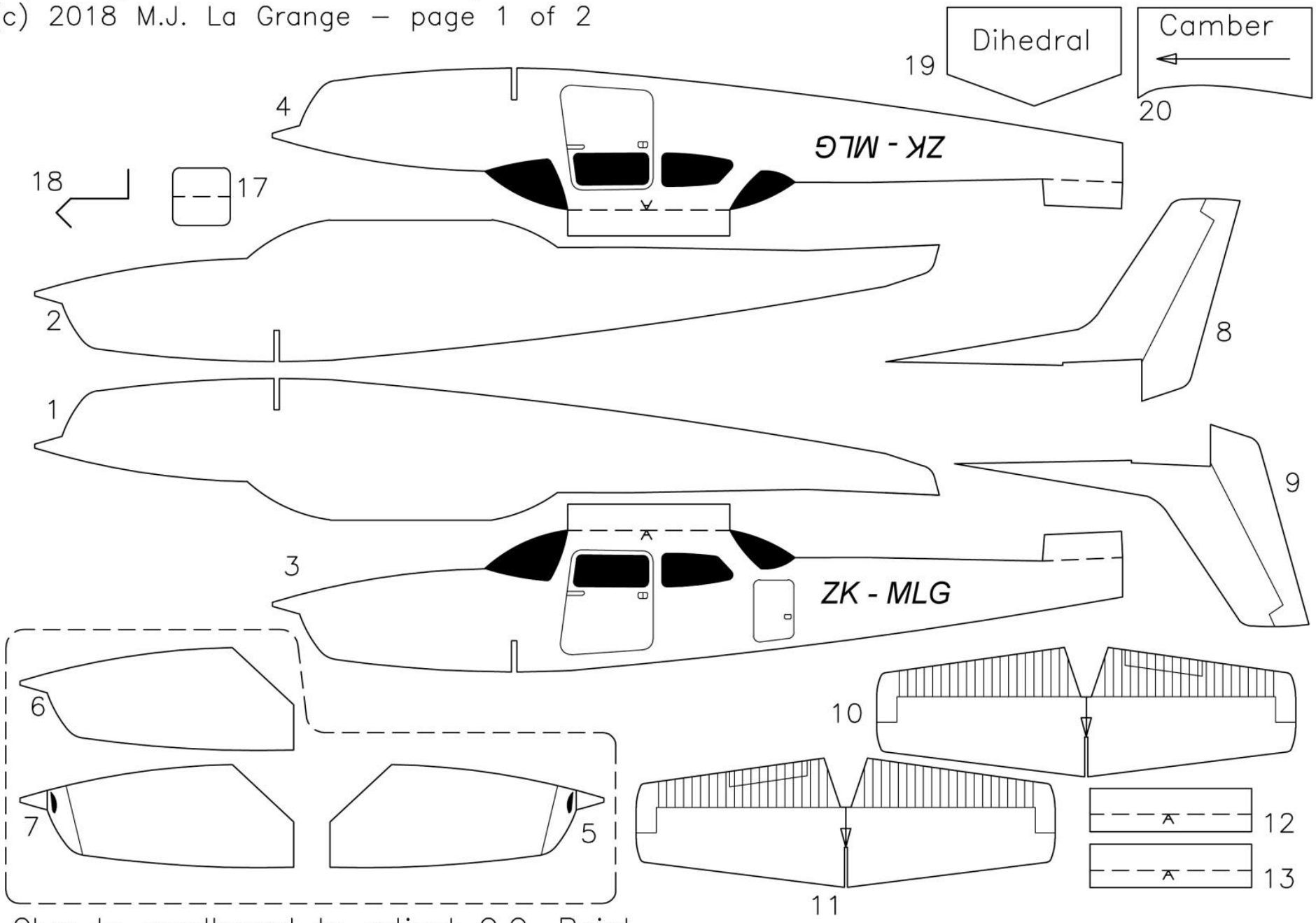
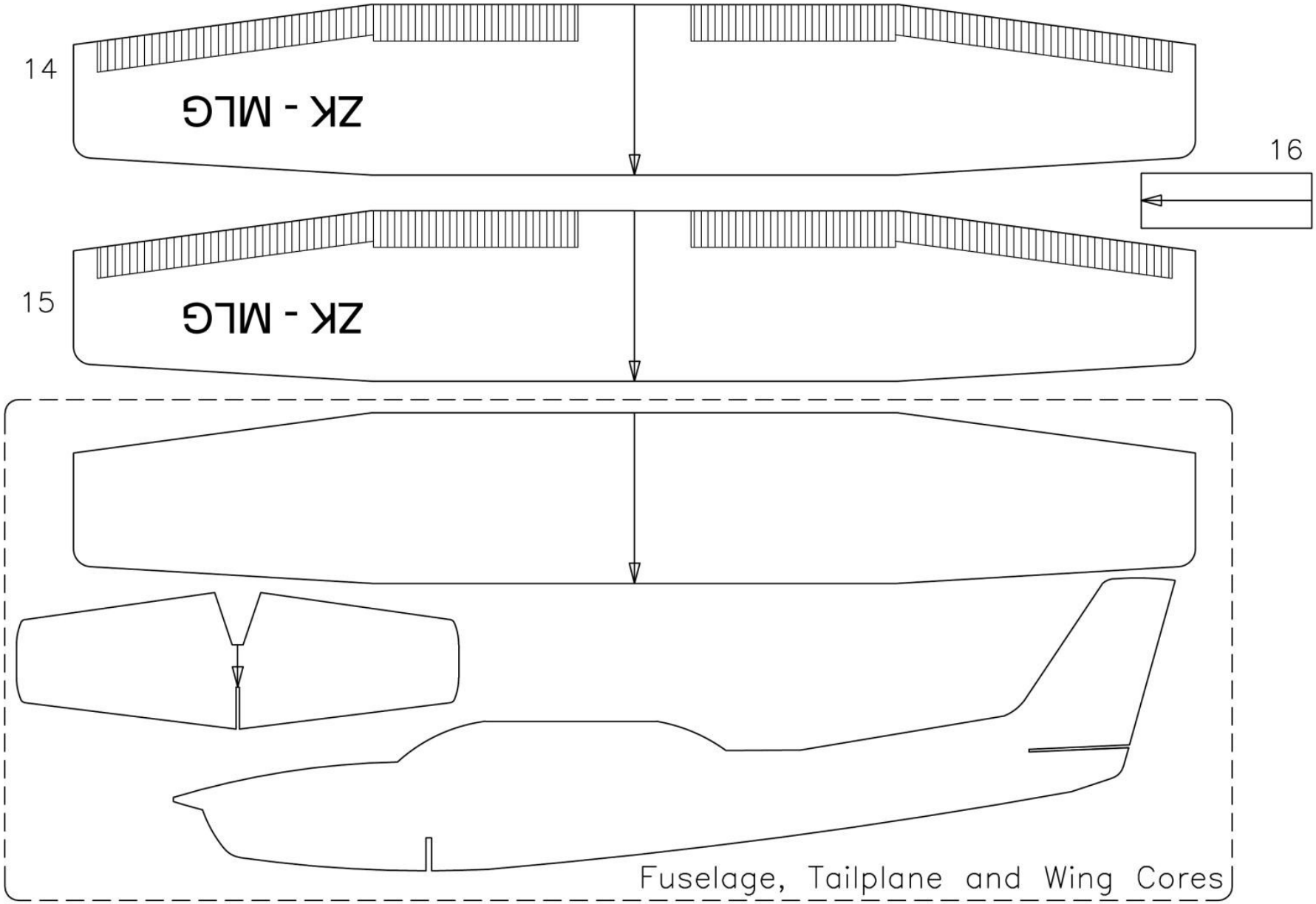


Glue to cardboard to adjust C.G. Point


14
ZK - MLG
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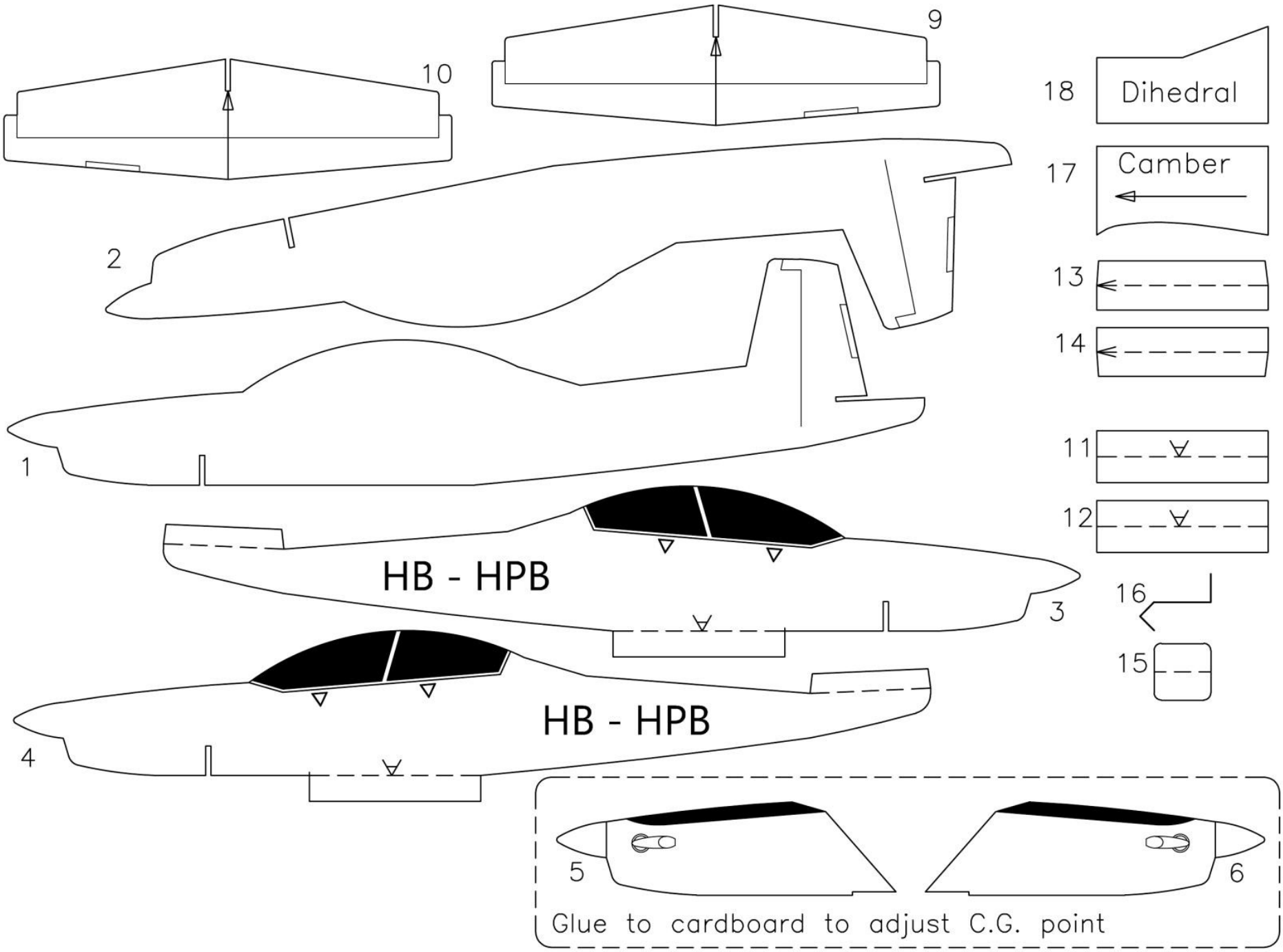
ZK - MLG
Fuselage, Tailplane and Wing Cores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Dihedral
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Camber
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Glue to cardboard to adjust C.G. point

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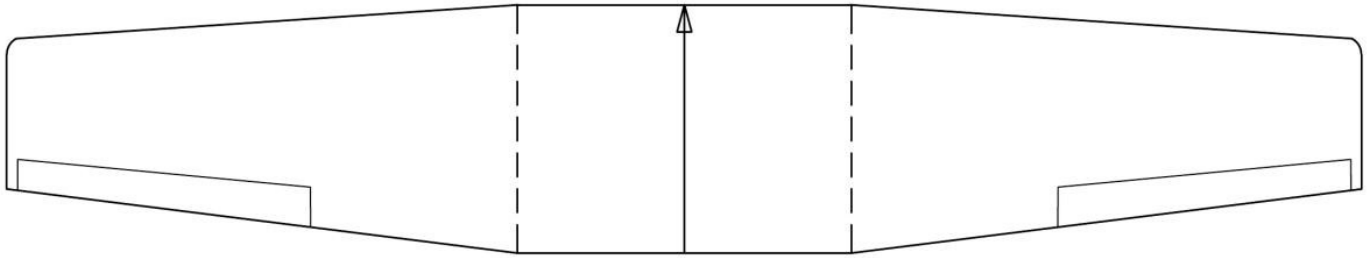

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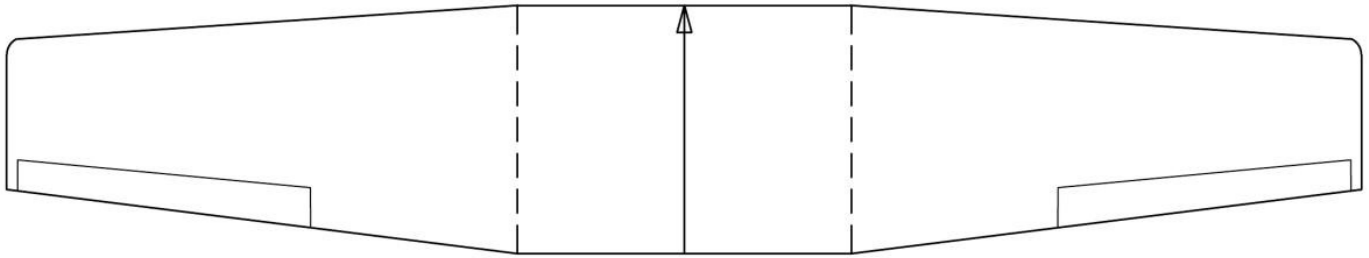

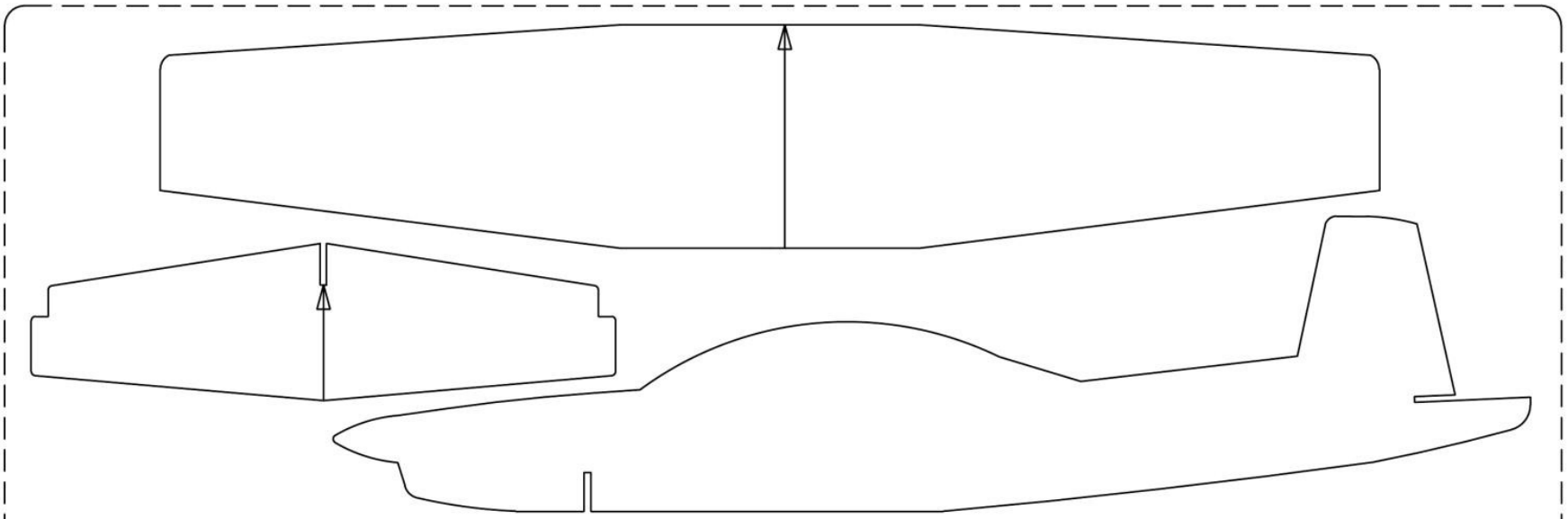

Wing, Tailplane and Fuselage Cores.

Paper Flight – Bombardier Dash–8 Q400
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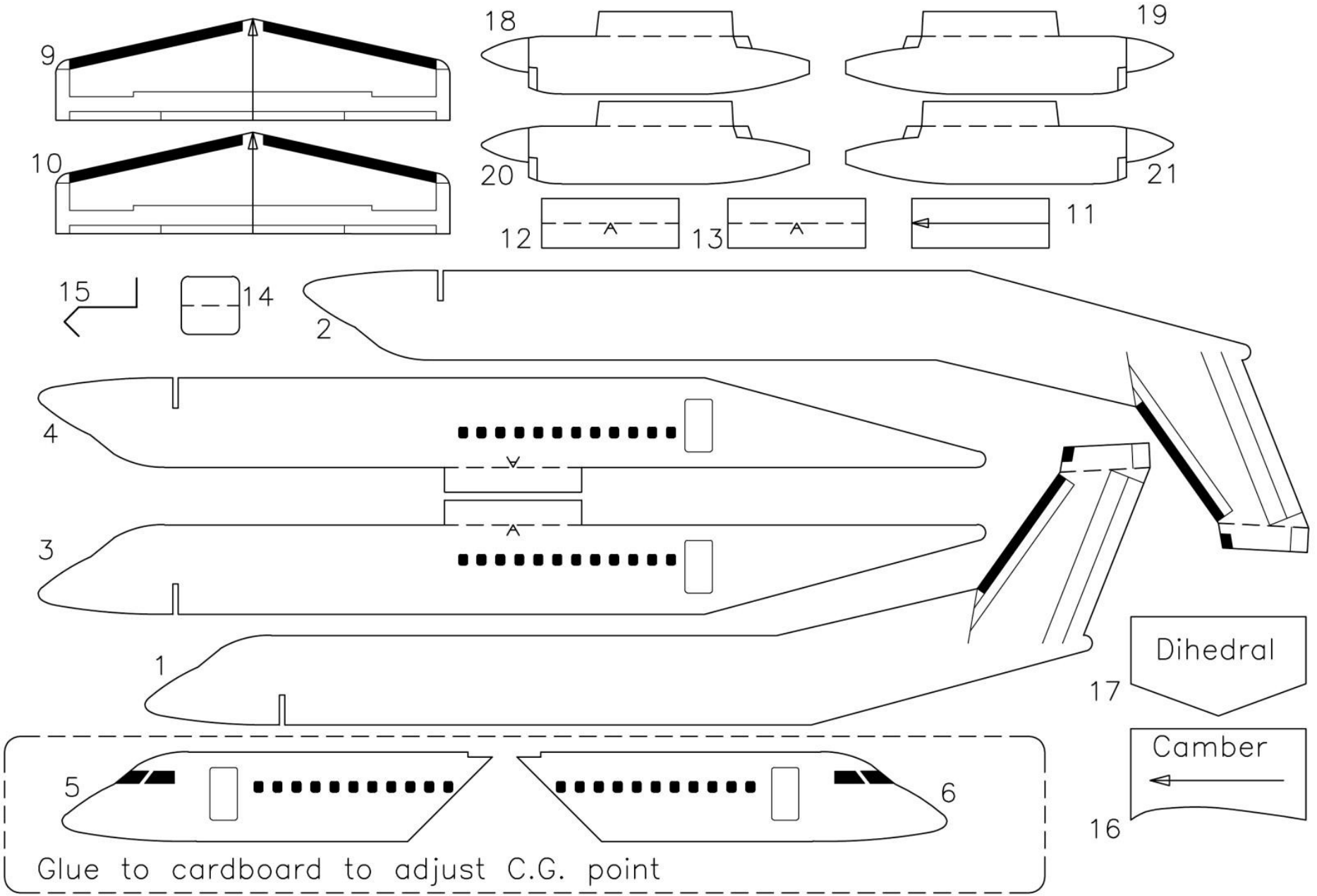

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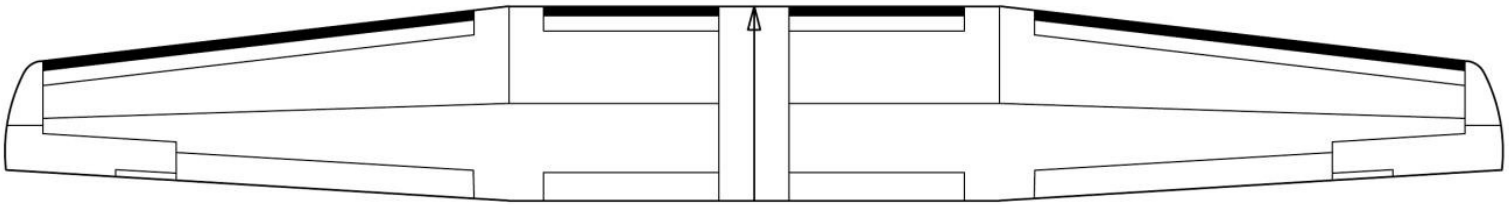

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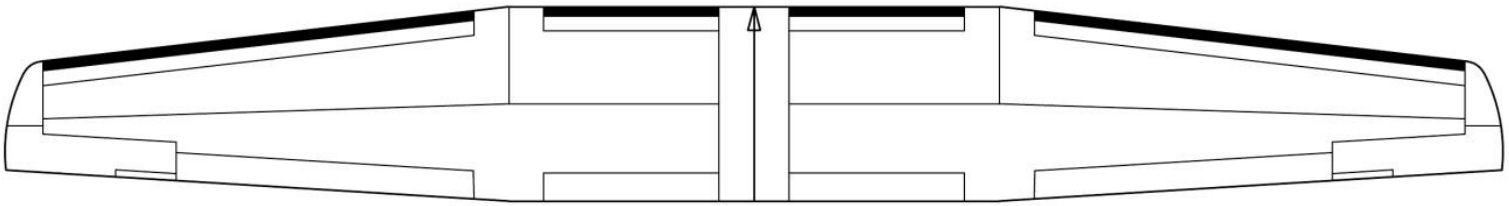

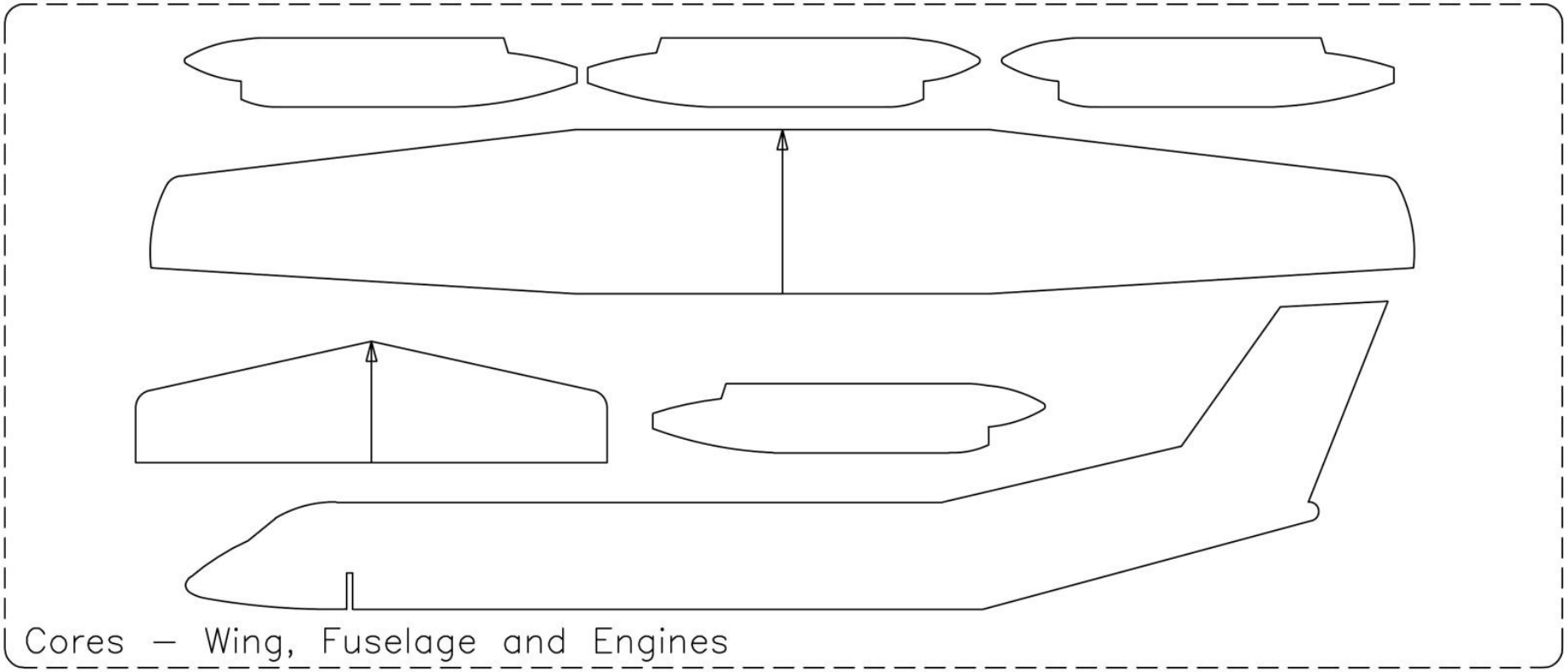

Cores – Wing, Fuselage and Engines

Paper Flight – Rockwell Aero Commander 840
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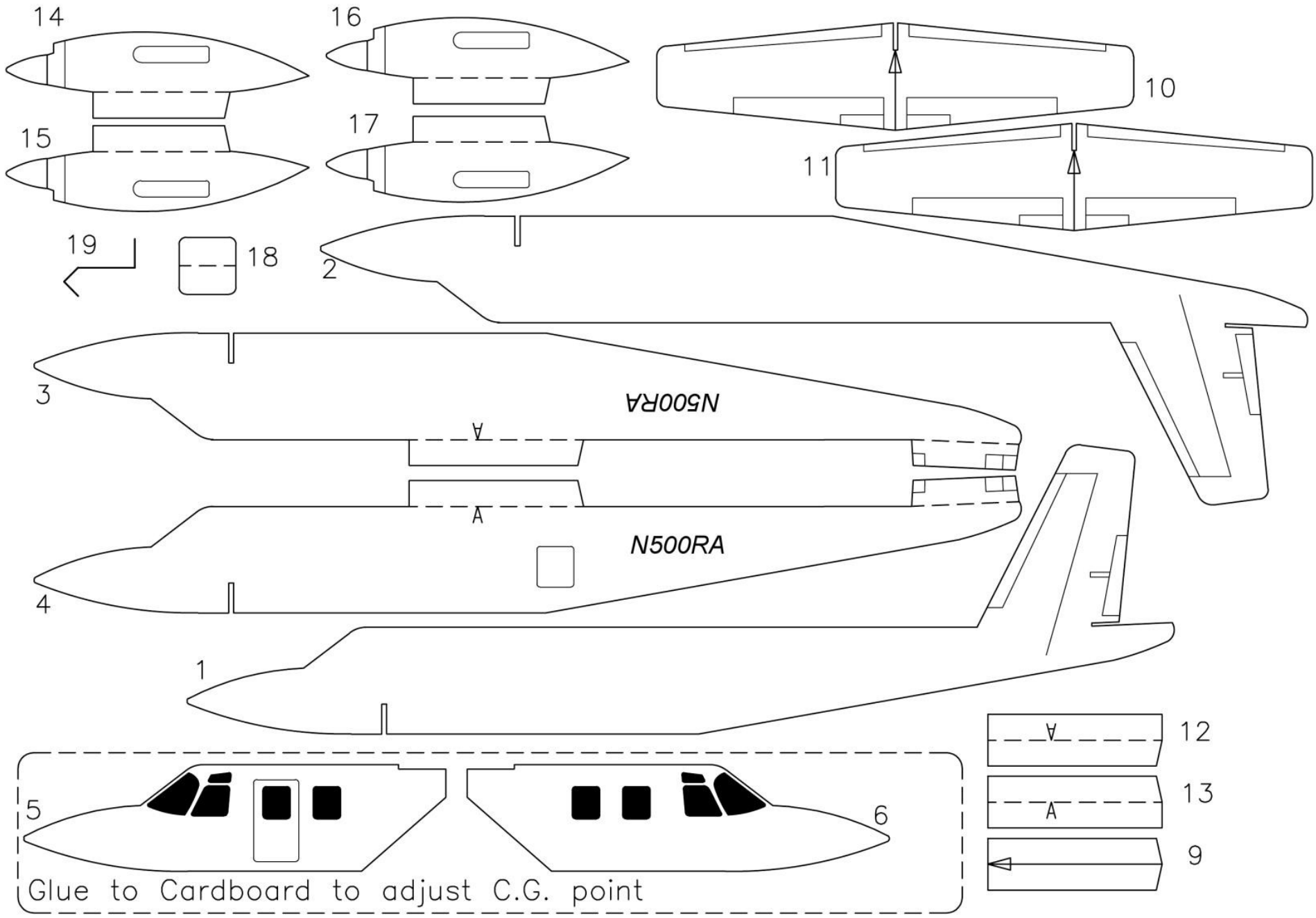

Paper Flight – Rockwell Aero Commander 840
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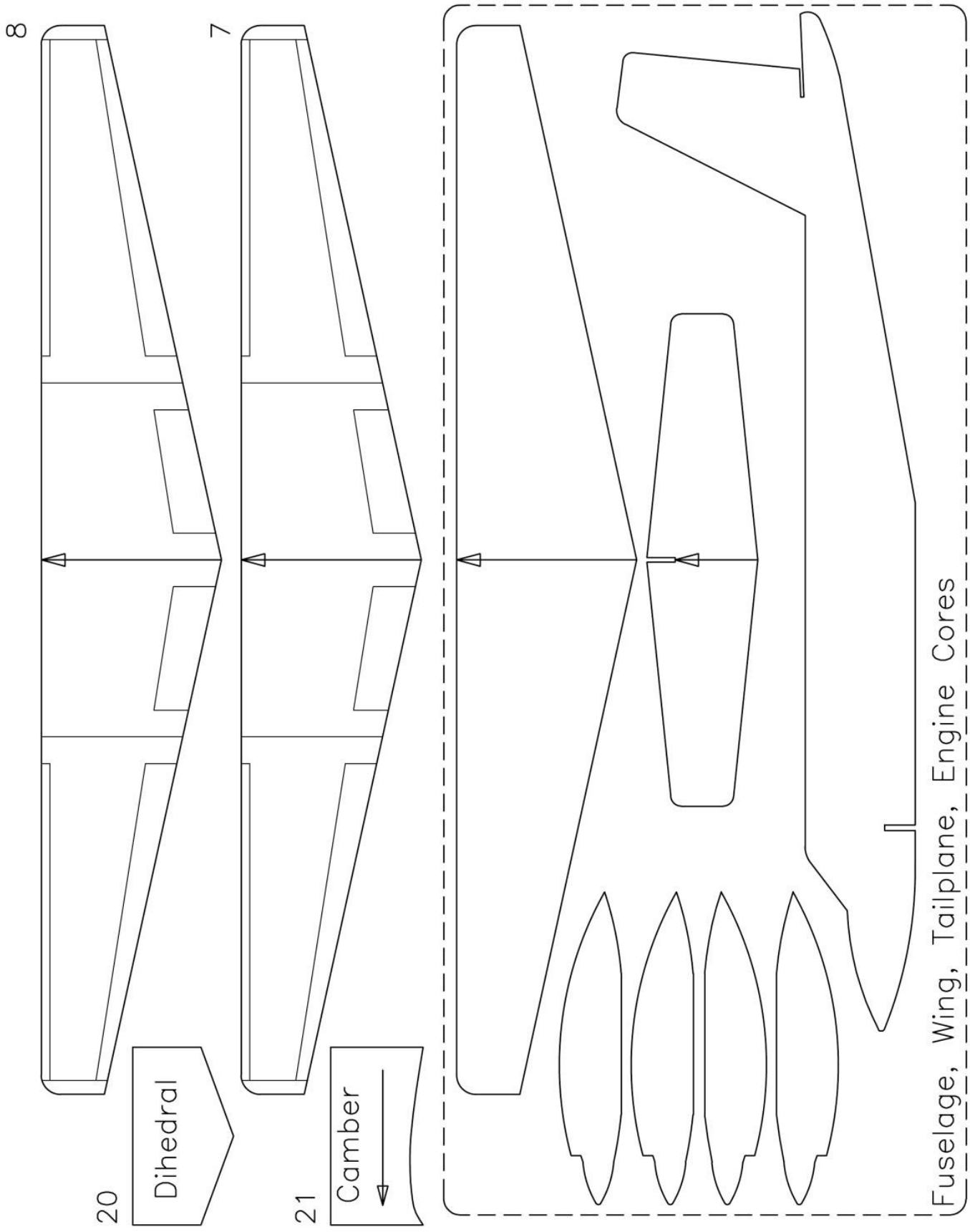
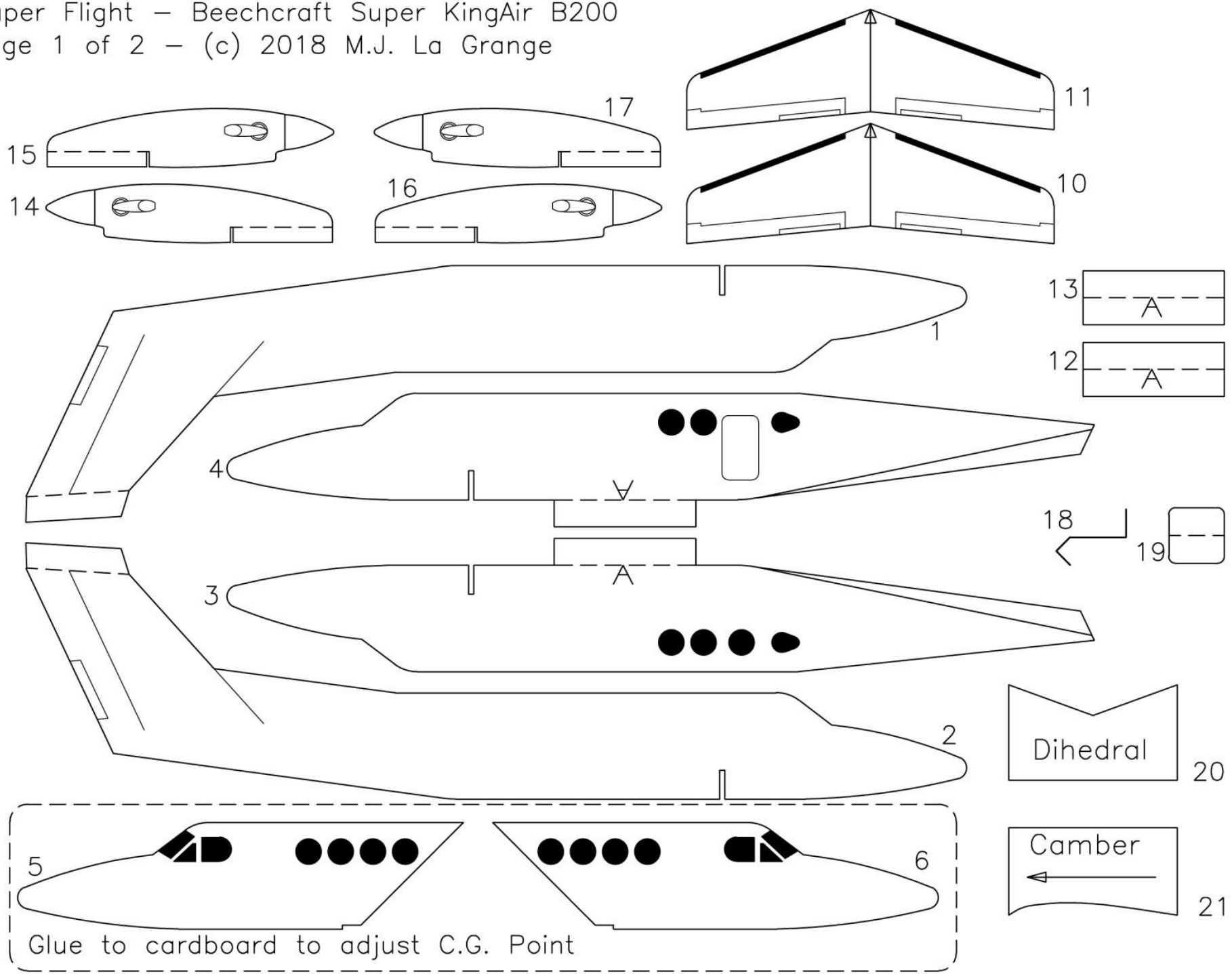
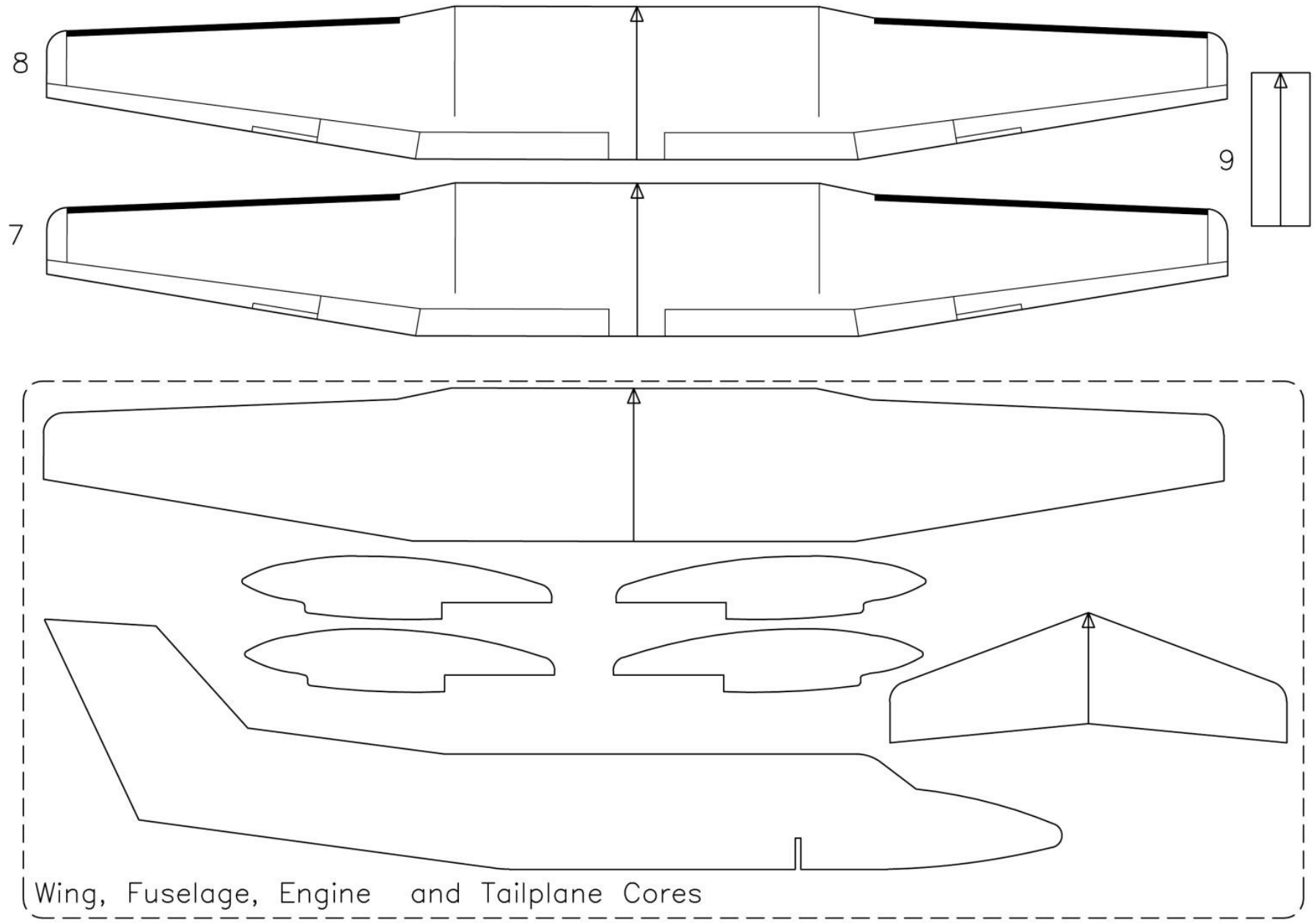
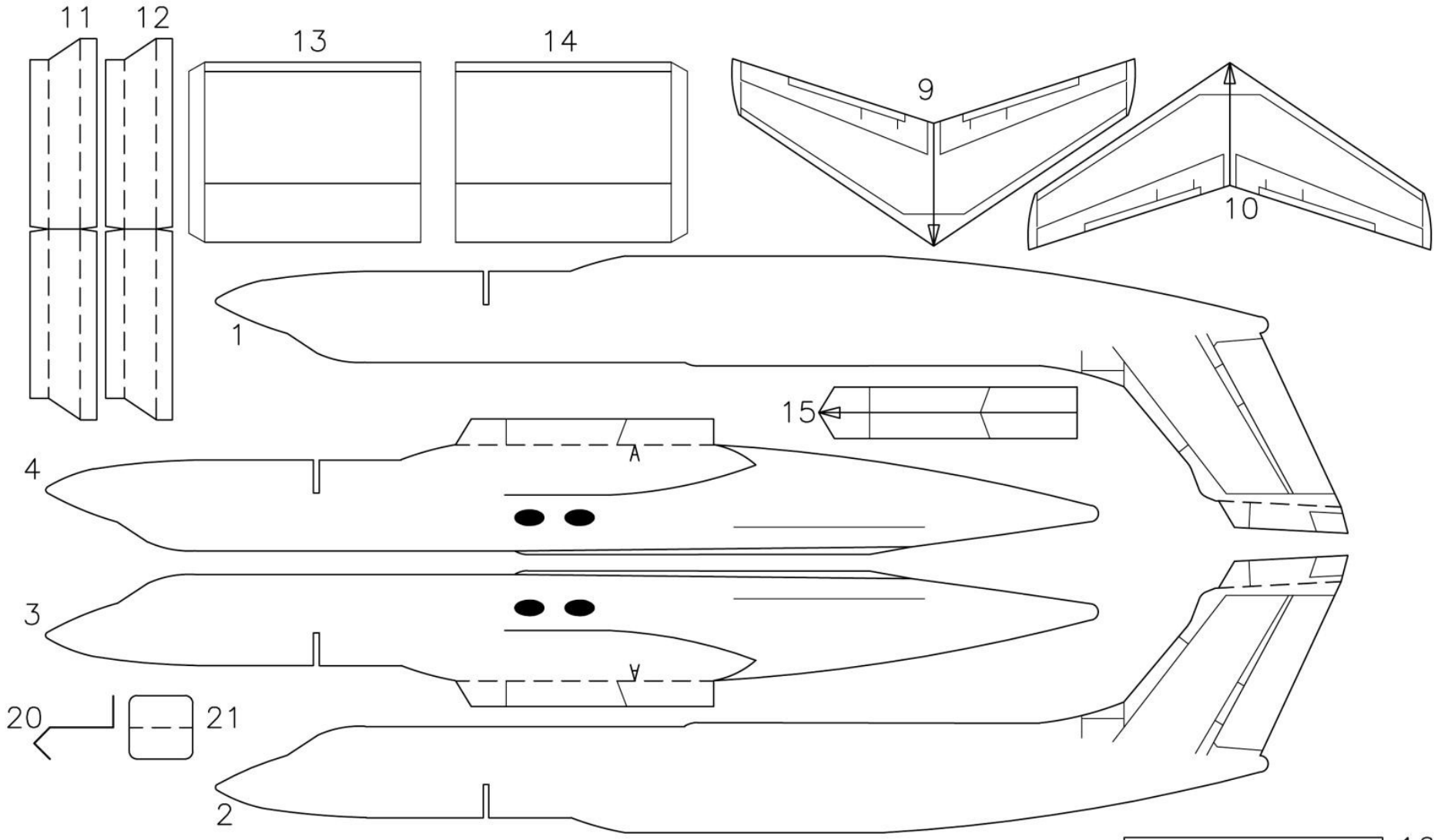


Paper Flight – Beechcraft Super KingAir B200
page 1 of 2 – (c) 2018 M.J. La Grange





Paper Flight – Beechcraft Super KingAir B200
 – (c) 2018 M.J. La Grange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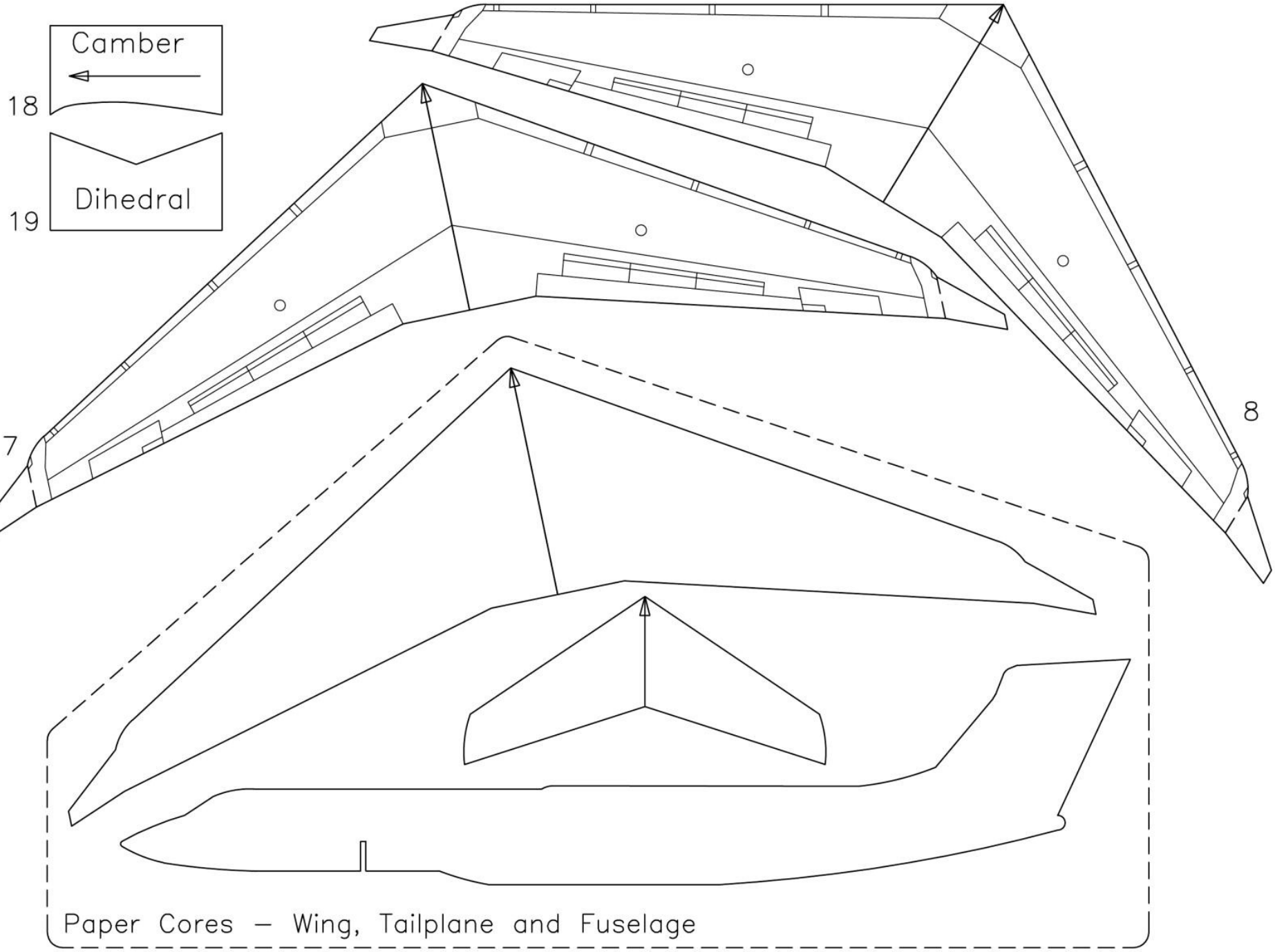
Glue to cardboard to adjust C.G. Point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Dihedral
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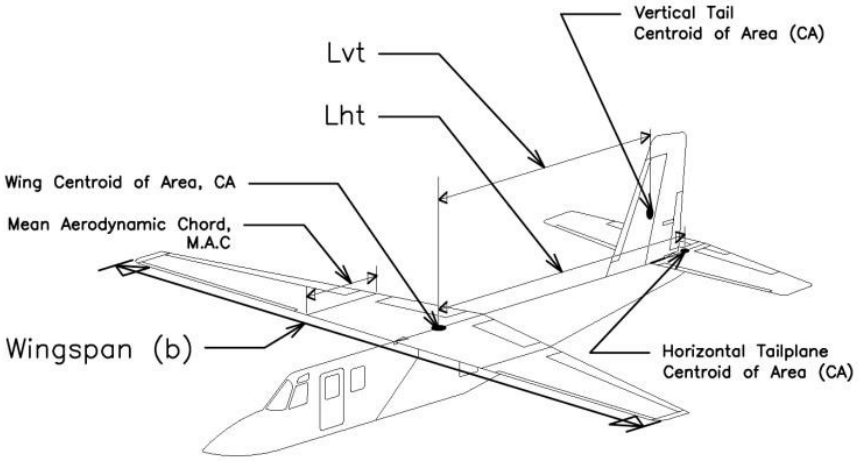
Paper Cores – Wing, Tailplane and Fuselage

7. Design your own models

To design a model aircraft , its very important to know some critical dimensions :



The critical dimensions are :

- Mean Aerdynamic Chord (MAC) of the wing
- Wingspan (b) of the wing
- Tailfin Centroid of Area (CA) and position (Lht)
- Tailplane Centroid of Area (CA) and position (Lvt)
- Areas of flying surfaces (in any decimal unit of measurement)

Length of fuselage also plays a role, from the perspective of model strength, and from the perspective of model balance around the Center of Gravity (CG).

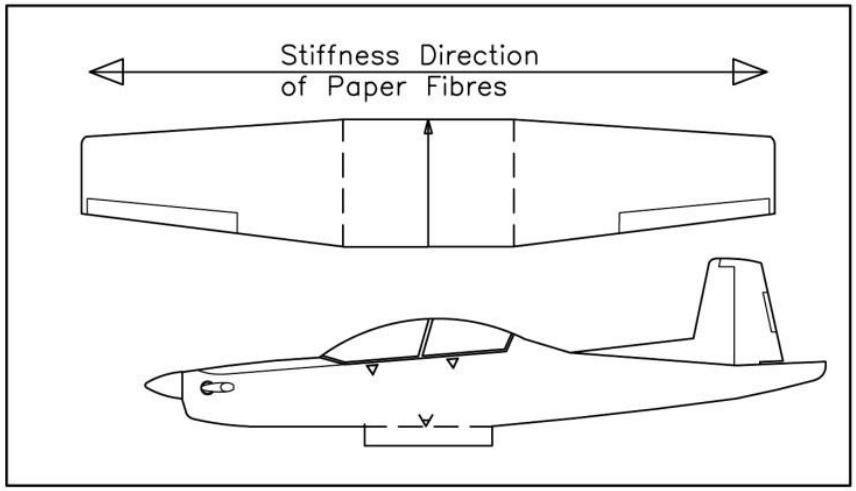
FLIGHT PERFORMANCE

The best way of increasing flight performance is to minimize drag, and increase lift. Keeping the model light, and making use of a cambered paper wing surface produces maximum lift.
This process known as **maximizing the L/D ratio**, and is a time-honoured aircraft design process for *all* aircraft, big and small.

STRUCTURAL STRENGTH

Paper aircraft gain their strength from the direction of the paper fibres running along the long edge of the sheet. By layering parts using this stiffness direction, the resulting paper model is both very strong and light.

This is very important, as the paper model must deform from the forces (lift, drag, and airspeed) imposed on it in flight.



STABILITY

To fly well, a paper aircraft must have stability, where it is able to resist being knocked off course by disturbances in the air as it flies.

The most important parts of a model design that keep flight stable are :

- Wing dihedral angle
- Angle of incidence between the wing and tailplane - this is known in aerodynamics as *decalage*, and is an important design feature.
- Position of the CG in relation to the wing MAC.
- Tail surface area - Sht (Horizontal tail) and Svt (Vertical Tail)

Dihedral

Wing dihedral should be great enough to help a model resist rolling forces in-flight. For a high wing model, a dihedral of 15 degrees is often sufficient. Low wing models have a greater dihedral than high wing models in general. Low wing models need a dihedral of 20-25 degrees **20 degrees dihedral from the horizontal is a good average value.**

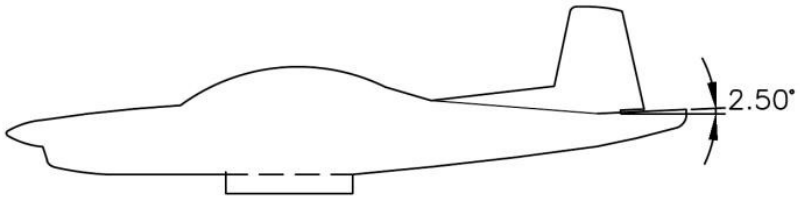
Tailplane angle of incidence - Decalage

The horizontal tailplane stabilises the model aircraft in flight (which is why it is often referred to, very correctly in United States English, as a *stabiliser*). It does so by producing downwards directed tailplane lift, in the opposite direction of wing lift. This can be adjusted by *trimming*.

However, if the tail plane angle is set at 0 degrees of incidence, then no stabilising down-lift is created as the model aircraft flies through the air. As designers, we can add a built-in up trim to our models by setting the tailplane angle of incidence from 0 degrees to any value we like.

From experience, the best angle for low and high winged paper aircraft with tails mounted nearly horizontal with the wing should be **2.5 degrees**.

For T-tailed model aircraft, this value can be increased to **3.5 degrees**.

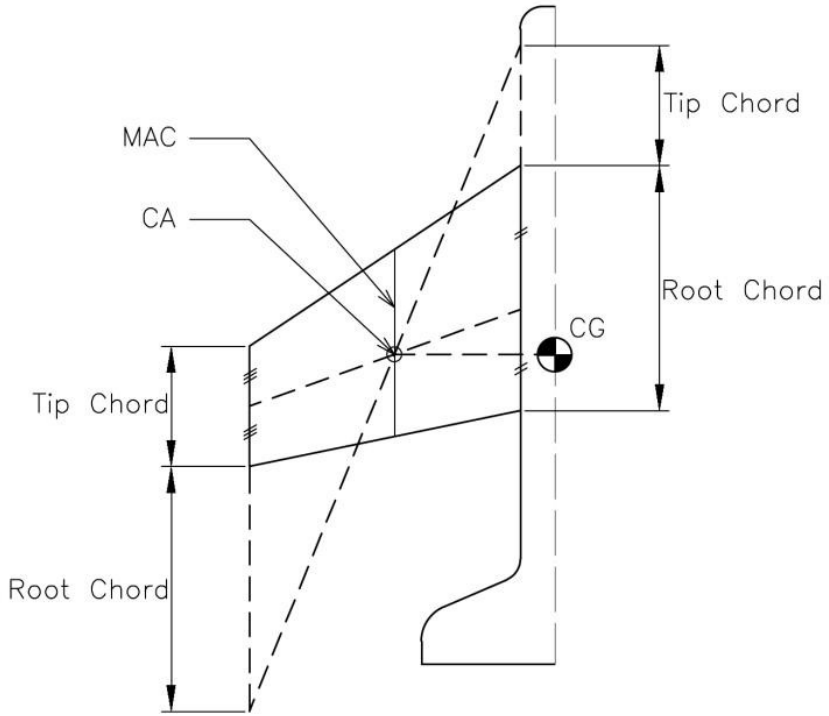


The Center of Gravity (C.G.) and the Mean Aerodynamic Chord (MAC)

The C.G. of the model should ideally share the same as the geometric position on the fuselage as the midpoint of the wing's Mean Aerodynamic Chord (MAC).

As an aircraft wing is almost never a rectangle, the MAC is almost never at the center of the wing.

It is possible of course to work out the MAC geometrically.
For a wing that is not too complex in shape, it is possible to do so with geometry, using the *Chord* (which is the width of the wing at any point) of the wing roots and wing tips to work out where what is known as the *Centroid of Area* (or CA) lies on the wing. The Wing Chord that passes through the CA is known as the *Mean Aerodynamic Chord*.

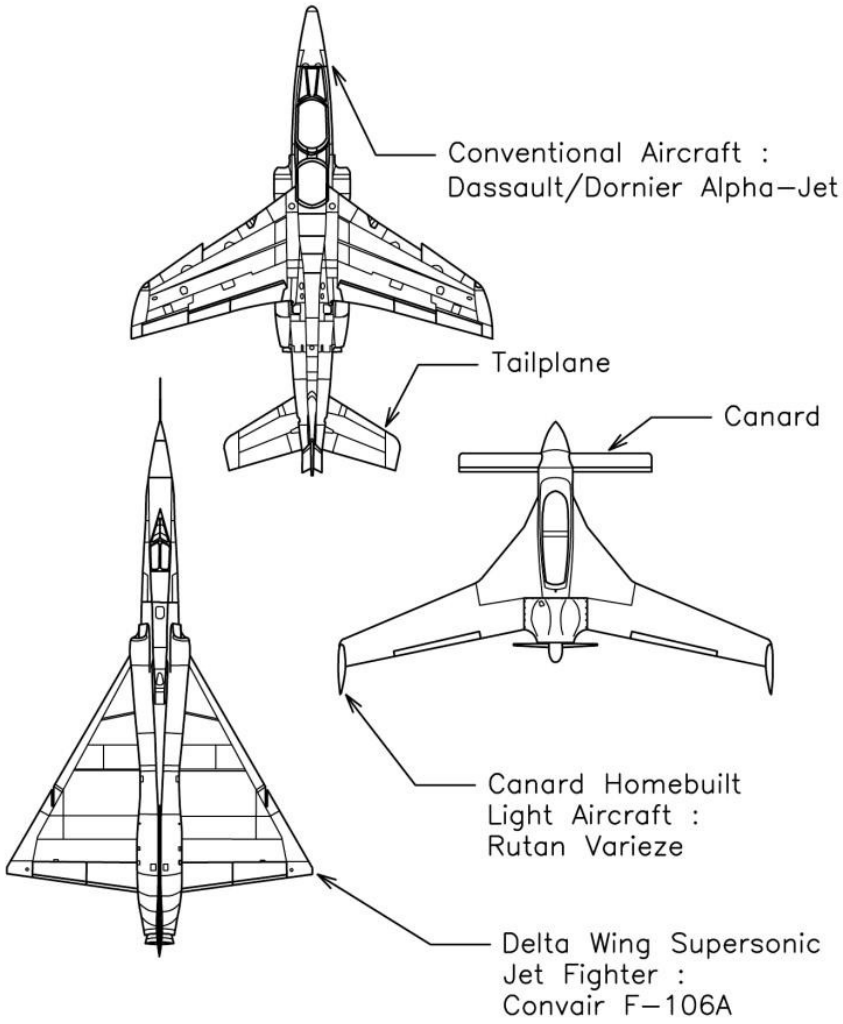


As you can see, the geometric construction allows an easy way to work out an MAC :

- A line from the midpoint of the Root Chord and Tip Chord is the first line to be drawn.
- With the use of the length of the Root Chord and Tip Chord added in the way illustrated, its then possible to draw a diagonal line with maximum extension from point to point.
- Where the diagonals cross is the **Centroid of Area (CA)** for the wing.
- The Chord parallel to the Root and Tip Chords, and passing through the CA is the **Mean Aerodynamic Chord (MAC)** of the wing.
- The perpendicular line (g) from the CA to the fuselage is the geometric position of the **Center of Gravity (C.G.)** of the model.

Tail surface areas

For all types of aircraft, tailfin surface area is essential to in-flight stability. For conventional aircraft, tailplane surface area is also just as essential. Canard aircraft can be thought of as having their small control surface as being ahead of the main wing, though the canard serves the same purpose as a tailplane.



Vertical and horizontal tail surface areas can be *calculated* with a degree of accuracy sufficient to allow the paper aircraft to fly with great stability in the air.

As paper aircraft have very little drag on their fuselages (particularly when the fuselage is a flat plate), the mathematical formulae used are the same as that of a perfect aircraft.

Here are the formula for working out the surface areas of the vertical and horizontal and vertical tail surface areas:

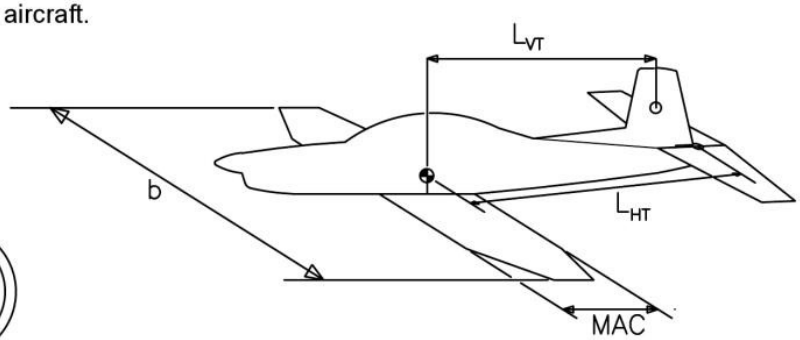
$$S_{HT} = (C_{HT} \times S_W \times MAC) / L_{HT}$$

$$S_{VT} = (C_{VT} \times S_W \times b) / L_{VT}$$

Where:

S_{HT}	=	The horizontal tail area.
S_{VT}	=	The vertical tail area.
S_W	=	The Wing total surface area (for both wings).
MAC	=	The *M*ean *A*erodynamic *Chord*, passing through the wing *C*entroid of *A*rea (CA).
b	=	The total wingspan.
L_{HT}	=	Distance from the Wing CA to the Horizontal Tailplane CA.
L_{VT}	=	Distance from the Wing CA to the Vertical Tailplane CA.
C_{HT}	=	Horizontal Tail Coefficient
C_{VT}	=	Vertical Tail Coefficient
x	=	multiplication symbol.

Centroid of area for each flying surface (Wing, Horizontal and Vertical Tailplane) is required to compute the best tail surface areas for the model aircraft.



To calculate the tail surface areas, it is necessary to have indicative horizontal and vertical tail volume coefficients - C_{HT} and C_{VT}.

Here is a table of these values for some well known civil airliners :

Aircraft	C_{HT}	C_{VT}
Bombardier Dash 8 Q400	1.520	0.103
Airbus ATR 72-200	1.113	0.101
Boeing 737-MAX	1.200	0.097
Boeing 747-8 Jumbo Jet	1.100	0.084

Full sized airliners need to have a good of horizontal stability for hands-off flight, and for passenger comfort. For highest performance, paper aircraft need to share that level of performance.

For this reason, a **C_{HT} of 1.10 is acceptable for paper model aircraft.**

Paper aircraft do not need to have as large a vertical tail surface as a full sized aircraft - and so the C_{VT} can be lower than 0.08 in value. Experiments have shown that there is a lower limit, though.

For these reasons, a **C_{VT} of 0.06 is acceptable for paper model aircraft.**

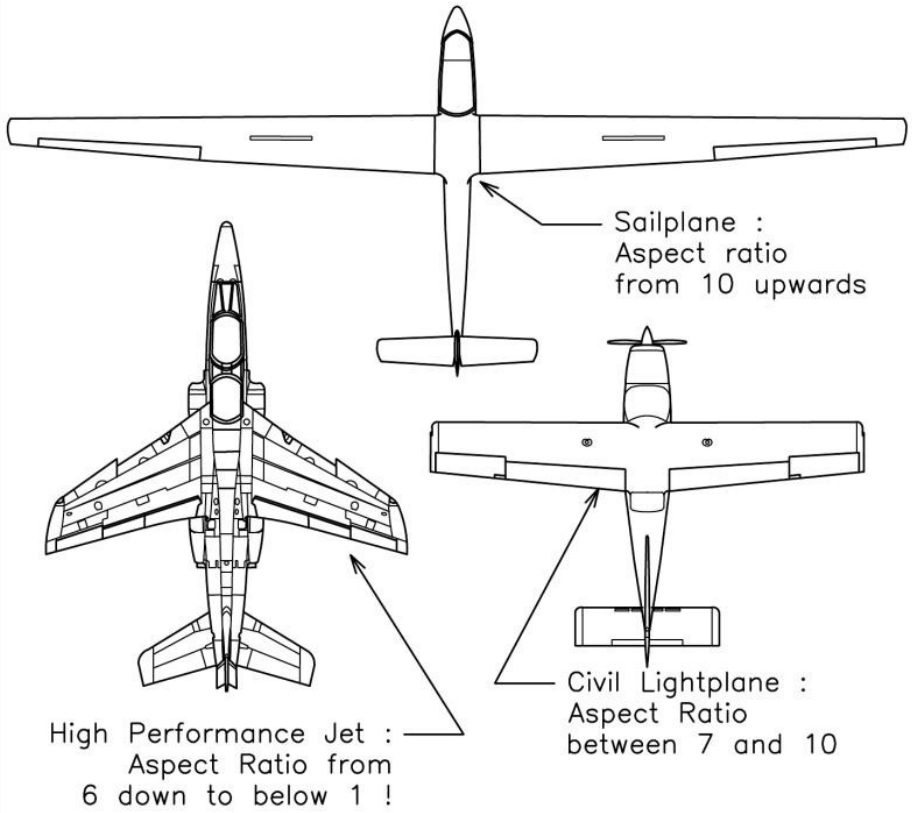
DESIGN CONSIDERATIONS

For best performance, a paper model aircraft needs to have an efficient wing planform shape.

If we take the example of the Convair F-106, a delta wing aeroplane compared with the Rutan Varieze, both aircraft have more or less the same overall main wing area. However, as gliders, the Varieze is able to fly with a far greater l/d ratio compared with the F-106. This is due to *Aspect Ratio*, which we can work out like this :

s = b / MAC for straight wing aircraft

$s = b^2 / SW$ for all possible wing shapes



From experience, the aspect ratio (symbol *s*) of the tail surfaces needs to be slightly smaller than that of the main wing surfaces.
In the example of the Cessna Skyhawk, the wing A.R., *s* = 8. For best tailplane efficiency, this should have a guide value we can work out like this :

Horizontal Tailplane *s* = Wing *s* - (Wing *s* / 4)

Resulting in a Tailplane *s* of 6 - though this is only a general guide.

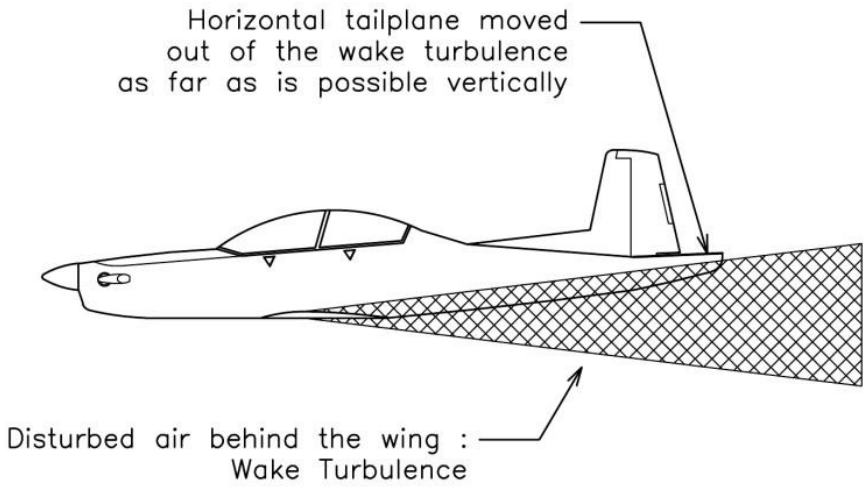
For vertical tail planes, the formula is :

Vertical Tail Plane *s* = Horizontal Tail Plane *s*

The vertical tailplane / fin needs to have the same aspect ratio for best efficiency, when providing in-flight stability for the model.

Full-sized aircraft keep the horizontal tailplane as far away horizontally from the wing as possible - this is due to the effect of the wing moving through the air, a phenomenon known as *wake turbulence*, and it affects paper aircraft too.

By seperating the horizontal tailplane from the wing's wake turbulence, the stabilising efficiency is increased, to result in smooth controllable flight.


Horizontal tailplane moved
out of the wake turbulence
as far as is possible vertically
Disturbed air behind the wing :
Wake Turbulence

Vertical tail surfaces *need* to be large enough to counter a flight tendency known as 'Dutch Roll', where if there is insufficient tail surface area, then the model aircraft tends to 'wiggle' as flies forward, which is highly undesirable. Flight testing eliminates this, to find a perfect surface area.

CAD (Computer Aided Design), and Spreadsheet software, make modern paper aircraft design to a high level of performance much easier, in terms of precision. These tools are today either free or very inexpensive.

With your skills and practice, you should be able to make your own high performance paper aircraft with ease.

8. Further Reading

Aeronautically Engineered Paper Aircraft Books

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Morris, C.D. (2015) **The Best Advanced Paper Airplane Compendium**, United States; Flight Time Ltd.

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Ojimak's World (2017) http://ojimak01.ehoh.net/index.html a compendium of 3D paper model aircraft, all of which can fly with varying degrees of good flight performance.

Ojimak's JASDF Models (2017) http://www.mod.go.jp/asdf/special/download/3d_paperplane/ Japan Air Self Defence Force models by Ojimak.

Zarkov Paper Models (2017) http://cadbest.com/store/en/free.php Some of the most beautiful high technology 3D CAD Model aircraft in the world can be found here.

Paper Replika (2017) http://paper-replika.com/ A wonderful resource containing a large number of beautiful paper models for free download.

GPM Card Models (2017) http://gpm.pl/en publishers of some of the most amazing and beautiful paper aircraft models in the world.

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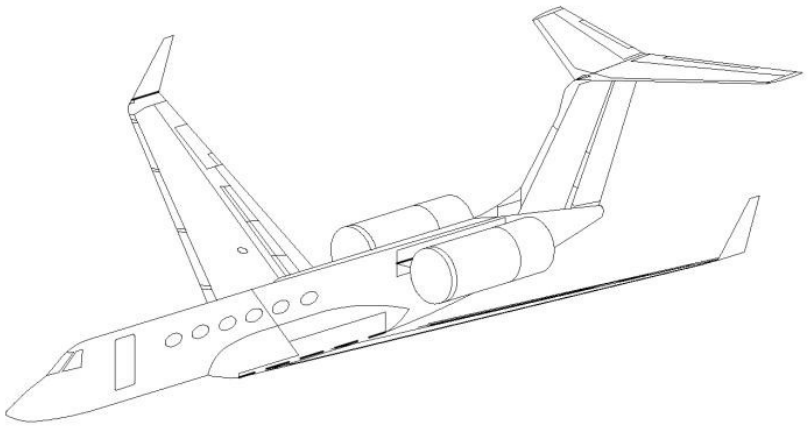

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